Mr. Milton Weiner
FILE

DEVELOPMENTS IN THEATER LEVEL WAR GAMES

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MATERIALS FOR THE C-5 WORKING GROUP "GAMING AND SIMULATION' OF THE 35TH SESSION OF THE MILITARY OPERATIONS RESEARCH SOCIETY

PREPARED BY:

ANTHONY H. CORDESMAN
CHIEF, PRODUCT EVALUATION DIVISION
OASD (INTELLIGENCE)
202-697-4436

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AGENDA OF THE
PANEL ON GAMING AND SIMULATION (C-5)

Chairman: Mr. Anthony H. Cordesman, Office of the Assistant Secretary of Defense (Intelligence)

Tuesday, 1 July 1975 -- 3:30 p.m. - 5:30 p.m.

3:30 - Opening Remarks

3:40 - Policy Level Needs for Improved Theater-Level Models
Dr. Henry H. Gaffney, Office of the Assistant Secretary of Defense (ISA)

4:30 - Net Assessment and Theater Level Modeling
Cdr Robin Pirie, Office of the Secretary of Defense (NA)
Dr. Phillip Karber, Office of the Secretary of Defense (NA)

Wednesday, 2 July 1975 -- 8:30 a.m. - 10:00 a.m.

8:30 - How New Theater-Level Models Improve Planning and Decision Making Capabilities: Part One

A short summary will be given of how the following new theater level models improve the U.S. capabilities for force planning, net assessment, military option planning and making major equipment trade offs.

8:30 - Vector Model
8:45 - Combat II
9:00 - Lulejian
9:15 - CEM
9:30 - IDAGAM

Wednesday, 2 July 1975 -- 1:30 p.m. - 3:10 p.m.

1:30 - How New Theater-Level Models Improve Planning and Decision Making Capabilities: Part Two

An open seminar discussion will be led by the Chairman with the participation of the entire working group. Its purpose will be a dialogue between modelers and model users covering the capabilities of new theater level games and planning or decision making requirements for further development and improvement.

Wednesday, 2 July 1975 -- 3:30 p.m. - 5:30 p.m.

3:30 - Comparison, Rationalization, and Standardization of Theater Level Models
Dr. Francis B. Kapper, Office of the Joint Chiefs of Staff (SAGA)

4:30 - Comparing Four "Next Generation" Theater Level Models
LTC Lanny Walker, Weapons Systems Evaluation Group

Thursday, 3 July 1975 -- 8:30 a.m. - 10:30 a.m.

8:30 - Panel discussion on Standardizing DoD-Wide Data and Intelligence Support Requirements for Theater Level and Other Models

9:30 - Wrap-up Discussion

ATWAR THEATER MODEL

The Assessment of Theater Warfare (ATWAR) model is the principal result of a study whose objective was to find an alternative to the single-valued measure of effectiveness (firepower scores) which currently drives most theater models.

The model has a hierarchical structure. The foundation of the structure is a set of combat samples. The set consists of eight levels of combat activity, or postures, for engaged Blue forces against a Red Combined Arms Army during 12 hours of combat, and the same eight postures for Blue against a Red Tank Army. From these samples, gamers determine the type and frequency of combat at platoon and company level in the engaged forces. The submodels of the Nonnuclear Ammunition Combat Rates Methodology operate on that data and on weapons performance data to assess personnel and equipment losses and ammunition expenditures in a single period of ground combat.

The ATWAR model divides the theater into 10 parallel sectors or less, Combined Arms Army or Tank Army sectors on the Red side, Corps or smaller sectors on the Blue side. The engaged forces are separated by a FEBA which moves independently in each sector in a direction parallel to that of the sector boundaries. Terrain is defined in four categories which are laid out chessboard fashion across the battlefield. The locations of good defensive terrain are further identified as "defensive positions" for use in the tactical decision logic described below.

The posture of opposing forces in each sector is determined by a tactical decision logic based upon user selected decision point criteria. The decision point is that fraction of a critical item of equipment or personnel below which the sector force cannot continue to maintain its existing posture. When a force falls below this point, it changes to a less agressive posture. If the change is from defense to delay, the force delays to the next defensive position where it will again attempt to defend. Movement rates in delay and withdrawal postures are stored in a lookup table indexed by terrain type and by posture.

A simple logistics routine allows onhand amunition stocks and transportation assets to affect the attrition process. If consumption of ammunition exceeds throughput capacity, causing unit stockage to fall below input stockage objective levels, the rate of attrition due to the type(s) of ammunition in short supply is reduced in direct proportion to the shortage. Logistics also affects the ground war by means of a repair cycle routine which returns a fraction of equipment losses to action after an appropriate delay.

The CONTACA*, a USACAA developed tactical air sortie and mission generator model, was integrated into ATWAR and modified to achieve an organic air/ground interface. The number of effective tactical air sorties on a daily basis is computed in CONTACA for the entire theater. A fraction of this is assigned to the land battle under investigation and transmitted into the ATWAR assessments routine where combat elements killed by effective sorties are computed and subtracted from sector forces.

The ATWAR model simulates a policy of individual replacement of men and equipment for the Blue side and a combination of individual and unit replacement for Red. Red and Blue assets available for individual replacement are specified in the input data in terms of numbers per day. The ATWAR model then replaces losses of personnel and equipment up to that specified number. If replacements are not sufficient to replace all losses, the replacements are distributed in proportion to shortfall by sector. If there are replacement divisions available in theater reserve, Red divisions are replaced when their user specified assets fall below a user specified breakpoint criterion.

The following data is output by ATWAR by combat cycle (12-hour period), by day, at campaign conclusion, or at other gamer specified intervals:

a. FEBA location by sector.

b. Total casualties and ground weapons systems losses by cause, including those to tactical air.

c. Status of ground weapons systems by type, including personnel, and by sector.

d. Tactical air availability, aborts, actual launches and losses by aircraft type, by wave, and by day.

e. Tactical air effective sorties by mission allocation, type aircraft, wave, day, and sector.

f. Status of aircraft following each wave commitment.

g. Data that would permit calculation of ammunition expenditures if needed.

*CONTACA: Conventional Tactical Air Model

2

The feature which sets ATWAR apart from most other theater models (aside from the nondependence on firepower scores or similar MOE) is its man-in-the-loop capability. The model, as implemented on CAA's UNIVAC 1108 computer, allows a gamer to maintain control of the game by interacting through an on-line keyboard. The gamer may choose the option of being notified at each impending change of posture at which time he may review the status of Red and Blue forces and elect to permit the automatic posture change or override it. He may also ask for an interupt at any given day of the game whether or not a change of posture is taking place. At any interupt, the gamer may ask for a status report, commit reserve units, create new sectors, modify parameters influencing the tactical decision logic, or influence the allocation of tactical air resources.

THE BDM CORPORATION

1920 Aline Avenue
Vienna, Virginia 22180
Phone (703) 893-0750

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THE COMBAT II MODEL
A STEP TOWARD AN INTEGRATED COMBAT ASSESSMENT

FOREWORD

This paper has three purposes:

- To describe the theoretical concepts leading to the COMBAT II model
- To highlight the strengths, limitations and proper uses of the model
- To describe an Integrated Combat assessment methodology and relate COMBAT II to this methodology.

The paper begins with a review of the concept of a dynamic hierarchy of military force analysis models. Theoretical difficulties are outlined, and tenets for dealing with these difficulties are suggested. The conceptual underpinnings of the COMBAT II model are described and the model is shown to satisfy the stated tenets. The strengths and limitations of the model are highlighted and proper and improper uses discussed. Future development is outlined.

There follows a methodology for an Integrated Combat assessment from the level of the small unit at the front up through the division, corps and theater level. Conceptual descriptions are given for the family of models comprising this methodology, and the role of COMBAT II is discussed.

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CHAPTER I
BACKGROUND

A. NEED FOR QUANTITATIVE ASSESSMENTS OF MILITARY CAPABILITIES

Assessment of military capability is very much an art form requiring careful judgements by seasoned military and civilian professionals. These judgements should never be supplanted. They can however, be greatly facilitated and improved through selected quantitative measures and assessments. The discipline of developing numerical measures of physical phenomena is referred to as modeling--hence it follows that, if properly used, mathematical models can be useful adjuncts to national defense decision making.

In fact, as issues become more complex and as the numbers of individuals involved in the decision process increase, it becomes ever more necessary to tie the debate into a logical structure and format through the use of models. Examples of current issues where this point applies are MBFR, Net Technical Assessment, Net Assessment, Air-Ground-Naval weapons procurement schedules, Research and Development priorities, and military manpower levels. The need for quantitative analysis of these issues is becoming increasingly critical due to the pressure of inflation on the real purchasing power of the Defense budget.

The utility of quantitative analyses of the above issues depends directly on the extent to which the models meet the needs of the problem, and the understanding the analysts and users have of the role of mathematical models as an adjunct to decision making, and not as a substitute for judgement. This paper therefore details properties that models must have to be useful, and discusses proper versus improper uses by analysts and decision makers. The point of departure is a description of the underlying concept of state-of-the-art military modeling theory: the modeling hierarchy.

B. MILITARY MODELING HIERARCHY CONCEPT

Figure I-1, taken from an earlier paper[1], displays the concept of a hierarchy of military models. The idea is to develop a family of models, each appropriate for a specified level of detail, and to pass necessary information from one level to the next. For example at the Engagement level, the probability of a single round killing a target might be computed using the highly detailed Joint Munitions Effectiveness Manual (JMEM) methodology. This result (say for an AP round fired at a tank) might then be fed into a tank-on-tank model at the Encounter level to determine a loss exchange ratio for tanks.

Another example of information flow is between the battle and the theater levels. A number of battles distributed both spatially and temporally occur within the theater. Some measure of military effectiveness is taken at each battle and fed into a theater model to determine a campaign outcome. Usually this measure is FEBA movement, although casualties are also recorded and passed.

C. APPROACHES TO SOLUTION OF HIERARCHY

Classically, development and operation of the hierarchy have been attempted from the direction of the lower levels (Engineering/toward the higher (theater)). This is called the "bottom to top" or "inside out" approach. This approach was probably adopted initially because operational and engineering factors can be dealt with in depth without explicit consideration of the enemy. Given the engineering detail for each specific weapon, the next logical step is to the binary situation of one-on-one, which can also be evaluated in great detail. The approach begins to falter however, when many-on-many situations occur, because the number of degrees of freedom in the problem increases enormously and direct calculation on simulation at engineering detail becomes impossible. Still this has remained the principal approach over the years, perhaps because investigators

---

[1] Indices of Effectiveness in General Purpose Force Analysis, J. R. Bode, BDM, October 1974

have been reluctant to drop detail for fear of losing track of those factors which drive the results--A fear of "throwing the baby out with the bath."

Regardless of its intuitive appeal, the "bottom up" approach described above has not yielded an operational modeling hierarchy. We believe this failure is due to the approach rather than the basic concept of a hierarchy. Instead of the "bottom up" approach, we propose a "topside down" or "outside in" approach to the solution of the hierarchy.

In other words, rather than compiling all the details of all the weapons and interactions, and attempting to preserve this detail up to theater level force-on-force analyses, we propose instead to first assess the problem at the theater level. We describe processes rather than the details of all the interactions, and we evaluate the contributions that each process makes to the outcome. We then proceed down the hierarchy by describing the driving processes in terms of additional details. In this way we track through the problem in terms of relevant detail, but we don't waste efforts on irrelevant details.

To develop the case for use of the "outside in" approach, we begin the next chapter by listing fundamental difficulties of the military force assessment problem.

LEVEL	ASSESSMENTS	TRADE-OFFS
Global ↕ Nations Geopolitics	Balance of Power Economics	National Objectives
Theater ↕ Forces Climatology Geography	Specific Military Objectives	Total Force Size, Composition, Deployment, Employment
Battle ↕ Units Weather Topography	Casualties Movement Rates Weapons Attrition	Numbers and Types of Units Unit Tactics
Encounter ↕ Multiple Weapons Types Ceiling/Visibility Terrain	Targets Killed per Day/Sortie Exchange Ratios	Weapons Mixes Sub-unit Tactics
Engagement ↕ Single Weapons Types Controlled Conditions	Probability of Killing a Single Target Probability of Loss to Single Attritor Type	Weapons Tactics and Design Features
Operations ↕ Weapon Properties	Endurance Range/Speed Fire Rate	Design Specifications
Engineering Weapon Configuration	Weight Power Size	Design Features

Figure I-1 Dialectical Hierarchy of Interactions (Showing Typical Characteristics of Levels)

CHAPTER II

FUNDAMENTAL DIFFICULTIES OF THE HIERARCHICAL MODELING CONCEPT

The key difficulties in solving the hierarchical modeling problem fall in four categories: complexity, level of aggregation/detail, lack of physical theory, and non-linearity. Each of these will be discussed briefly below.

A. COMPLEXITY

Simply stated, there are so many possibilities and choices of action in military activities that it is patently impossible to enumerate all the interactions that could be important. The amount of detail that can be considered in a particular application depends on the size and speed of the computer and the time available to develop complex inputs and analyze multifaceted output information. Many a model, although looking good on paper, has faltered because the computations and input/output are too cumbersome.

B. LEVEL OF AGGREGATION/DETAIL

To reduce complexity, attempts are made to aggregate classes of variables and interactions. For the chosen aggregate, average actions, interactions and results are assumed to represent the set of individual possibilities. For example it is commonplace in many models to aggregate the infantry soldier into a company. Here the model keeps track of companies, but not individual soldiers. If, say, an incoming artillery round falls in the company area, a fractional kill of the company is recorded, rather than registering the number of troops killed.

The problem with this aggregation is that extrapolation from troops (which are physically killed) to companies (which are abstractions) requires specific physical relationships to pertain among the individual troops which comprise the company. Suppose 100 troops in a company are arrayed in a circle of uniform density and radius 200 meters. If a "cookie cutter" weapon with a lethal radius of 199 meters falls at the center of

this circle it would theoretically kill all the troops, and hence kill one company. But if the 100 troops were arrayed on the perimeter of the 200 meter circle, the same weapon would kill nobody. This argument shows that keeping track of the company location alone is not enough. It is also necessary to assume a spatial distribution of the troops in the company.

The above problem also holds for the firepower of the aggregate unit (company in this example). Specific assumptions must be made regarding the weapons mix, targeting, fire discipline, ammunition consumption, etc. Usually these assumptions remain constant throughout the time of the military engagement that is modeled.

At this point the key problem with aggregation has probably occured to the reader. That problem is: How does one aggregate without biasing the results by the assumptions required for aggregation? An equivalent statement of this dilemma is: "What is the necessary level of detail to include?"

C. LACK OF PHYSICAL THEORY

A perplexing problem is the lack of a physical covering theory of military effectiveness. Unlike physics, there are no laws that enable direct computation of future histories when initial conditions are known. Consider for instance some questions relating to the term combat capability. What does it mean? In what terms is it defined? What contributes to it, and how? Military science has not progressed to the point of having disciplined logical answers to these questions.

Another fundamental problem is relating sizes, and firepower of opposing forces to resultant movement over the ground. There are widely scattered historical data in this area but no theory has been proposed which explains the great variance of the historical outcomes.

Several schemes have been proposed and used to define combat capability and to relate movement on the ground to capability. The most widely used is the Firepower Potential or Firepower Scores, described in the previous reference. A serious limitation of these measures is that they cannot be easily decomposed to establish the time history of the contribution that each element in the indicator makes to the final outcome.

D. NON-LINEARITY

Re-examining the concept of the modeling hierarchy in Figure I-1 reveals that the upper models (toward the theater level) are primarily resource allocation models. These models allocate tac air, ground units and supplies to determine where and when the battles will be fought, and the number of resource units to be allocated to each battle.

To perform these resource allocation calculations, the upper level models use interaction factors (kill factors, acquisition probabilities, munition consumption rates, etc.) that are developed in the lower level models and passed up the hierarchy. But the interaction factors themselves depend on the numbers of military elements involved in specific engagements, encounters and battles. Consequently there is a nonlinear process such as shown in Figure II-1 where the output of the higher levels depends on the lower levels which depend in turn on the output of the upper models.

To date, the non-linearity has proven intractable, and one is forced to use interaction factors that are constant or independent functions of time.

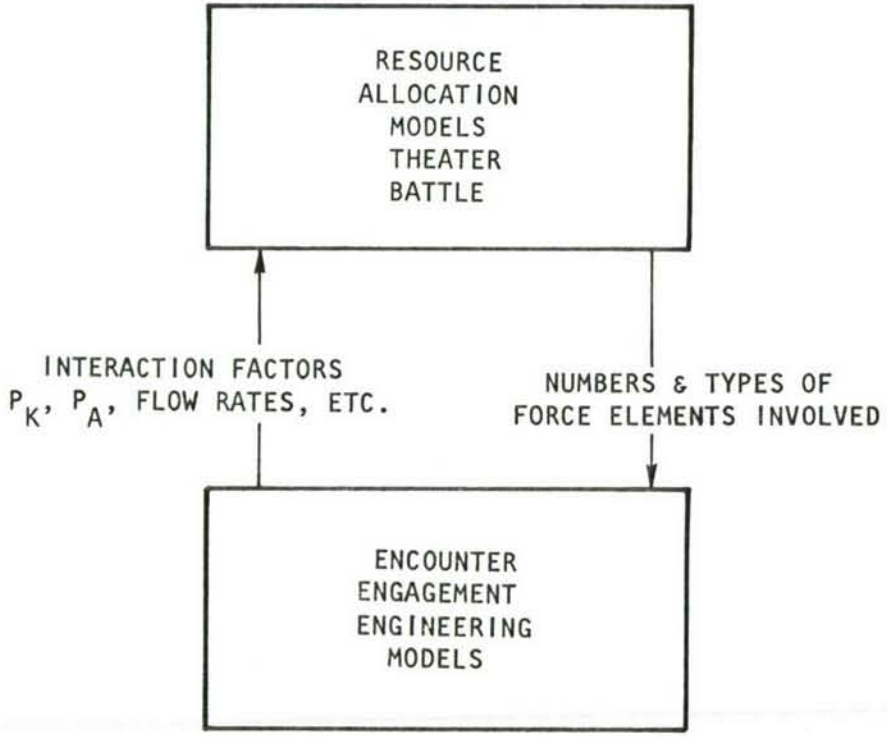


Figure II-2. Non-Linearity of Modeling Hierarchy

CHAPTER III

SUGGESTED TENETS FOR DEALING WITH DIFFICULTIES

This chapter proposes certain guidelines for dealing with complexity, aggregation/detail, and physical theory. Chapter VIII presents a concept for coping with non-linearity.

A. TENET 1 - TRANSPARENCY

This is the most basic of all tenets and at the same time the most widely disregarded. Simply stated the rule is that the model must be structured and programmed so that analysts and decision makers can understand what is going on inside. Said another way, the history of the contribution of each factor should be obtainable as a matter of routine. Then the driving variables can be identified and the nature of their effect analyzed.

Most models built in the past lacked the transparency property. This was probably due to programming difficulties. At any rate lack of transparency has contributed to a general disenchantment with "war game" models in recent years. However, we believe that with due attention to programming, transparency is readily achievable and that the COMBAT II model demonstrates this premise.

B. FUNDAMENTAL RULE OF DETAIL

This tenet is: Include details of only those interactions and factors that can be shown to influence the outcome.

This is essentially a school of thought, as contrasted to the school that proposes to include everything. An example will help clarify the argument.

Consider a maneuvering combat engagement between two air superiority fighters attacking each other with guns. During the early stages the stability and control derivatives are relatively unimportant--it is the energy maneuverability that determines whether a firing opportunity occurs or not. But given that a firing opportunity does occur, then the stability and

control may become important as a determinant of tracking difficulty. At this stage the sight and gun characteristics also become factors of interest.

There are two fundamental approaches to the above problem. Approach 1 would be to model the complete aircraft/pilot, sight, gun, and projectile systems in all the detail ever needed at any stage of the fight. This would be extremely expensive, time consuming to run and difficult to use. Approach 2 would characterize the performance of the subsystems (aircraft energy maneuverability, stability control, sight, gun, projectiles) by simple models on parametric variables, and exercise this "model of a model" parametrically to determine the region and boundaries of influence of each subsystem. Then the subsystem would be modeled to the extent required during its phase of significance. The rest of the time when it was not important the subsystem would not be modeled in detail. This of course is the "fundamental rule of detail" stated above.

The rule of detail implies that it is possible to determine those factors and interactions that determine the outcome. The mechanisms for doing this is the "top down" or "outside in" approach described briefly in section B above. Chapter IV shows how this can be done using the COMBAT II model.

C. HEURISTIC FORMULATIONS

These tenets deal with the fact that at some point in modeling, detailed descriptions of the interactions between physical things cease and estimation of relationships based on assumed capability measures begins. There are no known physical laws defining these capability measures or the relationships between them. Consequently it is necessary to develop heuristic formulations.

It is our thesis that necessary heuristic formulations are acceptable provided four tenets are met.

- Simplicity The mathematical formulation should be as simple as possible
- Symmetry The underlying model structure should be symmetrical for Red and Blue. Asymmetries should be dealt with through input

values. This way biases can be created and studied at will, rather than creeping into the model structure.

- Decomposable. The time history of the contribution of each variable/factor to the measure must be routinely obtainable as output. This is the way to find out what is important and what is not.
- Scalable. The results must be scalable to past conflicts or exercises, so that the outcome can be compared to judgement and intuition.

The heuristic formulations of COMBAT II are discussed in Chapter IV and shown to meet these tenets.

D. SPECIFIC APPLICABILITY

The previous tenets are based primarily on logic and common sense. This tenet is based on experience which may or may not hold for the future. However, it should be highlighted. The tenet is that in order to build a useful model in a reasonable period of time it is necessary to focus on a specific problem. Unless one knows what the problem is, it is impossible to construct a useful model. Many have tried and failed.

On the other hand, a little thought given to flexibility when building a model for one application often has resulted in much wider utility. It is our opinion that provisions for extension should be made during development. However, actual extension to areas irrelevant to the stated problems should not be made. In other words, never put in any more detail than the problem warrants (rule of detail), but build a flexible architecture to facilitate later extensions.

E. PROPER USE OF MILITARY MODELS

A model that meets the tenets above can provide a powerful tool for illuminating key issues. There are however, two key points relative to use.

- The model must be used to compute numerical results to aid the decision makers judgement and intuition, and never be used to replace

judgement. In other words the model should do the work, the humans should do the thinking.

- The state-of-the-art models (including a 2nd generation model such as COMBAT II) can be excellent tools for comparative analyses. They cannot be used to predict absolute real world results, even if they are scaled to history. The theory just isn't here.

CHAPTER IV
CONCEPTS OF COMBAT II

The previous chapters described the modeling hierarchy and stated desirable tenets for the properties and use of mathematical models. This chapter describes the foundations of COMBAT II and shows that COMBAT II meets the desirable tenets.

A. HEURISTIC FORMULATIONS IN COMBAT II

The primary purpose of COMBAT II is to calculate time-dependent attritions of the interacting combat systems throughout the theater. For tactical missile exchanges, most aircraft interactions, and ground force interactions over a period of a few hours, these attritions may be determined without considering ground unit movements. However, for larger periods of combat and for developing supply and reinforcement flows, it is desirable to include a function that specifies a rate of ground force advance as a function of the number and effectiveness of the forces on each side. There is no known set of physical laws that specify movement as a function of the combat elements involved. Consequently, any relationship between movement and forces must be largely heuristic. Even so, useful results are obtainable if the movement equation treats each side symmetrically. This has been done in COMBAT II. The following heuristic formulations are defined in the model.

1. Combat Capability Measures

Let B and R stand, respectively, for the strengths of the Blue and Red opposing ground forces. Let δB and δR stand, respectively, for the total attrition rates, from all causes, of the Blue and Red opposing forces. A heuristic measure of the relative combat effectiveness of the Blue and Red forces was taken to be:

$$\frac{\frac{\delta R}{R}}{\frac{\delta R}{R} + \frac{\delta B}{B}} \qquad \text{for Blue}$$

AND

$$\frac{\frac{\delta B}{B}}{\frac{\delta R}{R} + \frac{\delta B}{B}} \quad \text{for Red}$$

The measure basically says that the side with the greater effectiveness is the side that is inflicting the higher normalized fractional attrition rate on the opposing force.

The difference of the Blue and Red effectiveness measures was defined as a function, r, and is given by:

$$r = \frac{\frac{\delta R}{R} - \frac{\delta B}{B}}{\frac{\delta R}{R} + \frac{\delta B}{B}}$$

The function r is symmetrical with respect to the Blue and Red forces and varies between +1 when the situation is highly Blue favorable, to -1 when it is highly Red favorable. The purpose in defining r was to use it subsequently as the driving function for FEBA movement.

It may be noted that the expression for r may be simplified to read:

$$r = \frac{B\delta R - R\delta B}{B\delta R + R\delta B}$$

In this formulation it is readily seen that the definition of r as a FEBA driver is consistent with simple Lanchester theory.

In Lanchester theory the attrition rate of either side is simply proportional to the numerical strength of the other side.* Thus $\delta R = \alpha B$ and $\delta B = \lambda R$ where α and λ are measures of the unit effectiveness of the opposing Blue and Red forces. Lanchester theory shows that initial values of the quantities αB^2 and λR^2 determine which side wins. If αB^2 initially is greater than λR^2, Blue wins, otherwise Blue loses. Thus in Lanchester theory αB^2 and λR^2 are measures of the combat capability of the opposing forces.

---

*This assumption leads to the Lanchester Square law. The assumption of a constant attrition rate leads to the linear law. Actually, in computing δB or δR in COMBAT II, neither of these assumptions is made. The model considers the composition of B and R, (tanks, infantry, artillery, etc.) and all the contributors to δB and δR (opposing ground forces, nuclear artillery, enemy air, etc.) and accepts coefficients to describe each interaction. These coefficients may be chosen to reflect one side or the other on the offensive.

We note that in Lanchester theory the:

quantity $B\delta R$ becomes αB^2

and $R\delta B$ becomes λR^2

Thus our general formulation for r agrees with Lanchester theory in that the side with the greater combat capability is the presently winning side.

Recall the four characteristics desired in heuristic formulations: simple, symmetrical, decomposable and scalable. It can be seen that the formulation for r meets the first three requirements. The function is simple, is continuous, has continuous derivatives and varies smoothly between plus and minus one. The function is obviously symmetrical.

Decomposition is provided for in the programming by keeping track of the contribution of each attacking system to the total instantaneous attrition rate. For example the attrition rate of Red, δR, is the sum of the instantaneous attrition due to all Blue conventional ground forces and artillery, plus the attrition due to Blue nuclear artillery, plus attrition due to Blue missiles such as Lance, plus attrition to central missiles such as Pershing, plus attrition due to each type of Blue aircraft. Each of the terms in this sum is calculated separately and added to make the total δR, so that it is possible to evaluate the history of the contribution that each component makes to Reds' attrition rate.

The fourth heuristic property, designed to be scalable, is provided for in the FEBA rate formulation discussed next.

2. FEBA Movement

The equation for r shows that when a force is unopposed the value of r is ± 1. Under these conditions the force should be advancing at the maximum possible rate, $(\dot{X}_{MAX})$, determined by terrain, weather, etc. When opposing forces are equally effective, i.e., when $B\delta R = R\delta B$ the value of r is zero. Under these conditions neither force should be advancing.

The equation used to represent the FEBA movement rate was selected to agree at these points. It also has the properties that both sides are treated symmetrically and that small values of r produce relatively little movement. The equation and its graph are shown in Figure IV-1.

Here FEBA rate scaling takes place. Two kinds of scaling are possible. The coefficients on r and r^5 determine the shape of the quintic. In the case shown, when $r = 1/2$ the FEBA rate is 26 percent of the maximum

FEBA MOVEMENT RATE = $\dot{X}$

$$\dot{X} = \dot{X}_{max} \left[.489r + .511r^5 \right]$$

GRAPHIC ILLUSTRATION OF FUNCTION

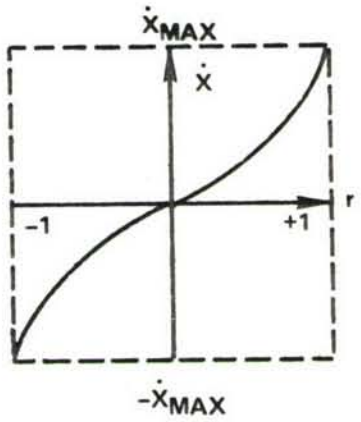


Figure IV-1. FEBA Movement Rate Equation

achievable for the given terrain, weather and force composition. Of course other scaling factors could be used, and the model is designed to facilitate examination of the sensitivity of results to the scaling factor chosen.

The second scaling factor is the value for $\dot{X}_{MAX}$, the maximum allowable FEBA movement rate. This is an input based on knowledge of the terrain, etc. The same comments as above pertain to sensitivity analyses. It is important to note that the FEBA rate is a function of r, but nothing in the model is a function of the FEBA rate. This avoids compounding errors inherent in the heuristic formulation of FEBA rate.

In addition to the r and FEBA rate formulations, COMBAT II has heuristic demand-response relations, described below.

3. Front Commands and Demand-Response Relations

COMBAT II currently plays three fronts. The actual movement of these fronts is dependent on the value of r, and $\dot{X}_{MAX}$ for each front as described in the preceeding section. Each front, on each side, Red and Blue, however, has a commanded rate of movement. Thus there are six commanded rates. In any front the actual movement rate is normally different from the two opposing commanded rates.

For Front 1 (one of the three chosen for the main attack), the Red and Blue command rates are unconditional. They are user chosen input numbers. Front 1 is the main one in which the principal effort is made by the attacking side. Fronts 2 and 3 are secondary Fronts used to maintain pressure through supporting attacks. They may be tightly or loosely coupled to Front 1 but they are coupled.

This coupling is achieved by making the commands in these fronts conditional upon the success achieved in Front 1. Thus Fronts 2 and 3 are commanded to advance at a certain fraction of the rate, not commanded, but actually achieved in Front 1. That fraction is a user input.

These commands enter into the model through the demand equations. They condition the demand for reinforcements and supplies that each frontal commander makes on his rear area. * When the actual FEBA movement rate exceeds that commanded the demand can go negative, indicating the commander's

*Time histories of specific units are not followed, and fractions of units are allowed. This is not felt to be a serious flaw since, at the theater level, large numbers of units are involved and, as in macrophysics, quantum effects should be unimportant. Supply packets can be moved, command, attrited, and their numbers accounted for similar to ground force packets.

willingness to shift forces to the rear where they are then available to the positive demand of other fronts.

Figure IV-2 shows the typical demand and response equations as they exist in the model. In the demand equation there are three limiting factors. First, a maximum allowable density is input to the model as a policy decision. Thus, if the commander desires that his forces maintain nuclear density, this is input. Although the code allows this to be changed at any time-step, the change must be input prior to processing. The code then limits demand according to the maximum allowable density.

Another limiting factor is the difference between the actual and commanded advance rate with demand being greater as the difference between commanded and actual rates increase. Demand can be negative if the actual rate exceeds the commanded rate.

Finally, the scale factor allows input of the impact of mobility conditions--terrain, weather, etc.--into the model.

Flow equations which respond to demand depend on the maximum flow rate, an input to the code. When demand is positive and large, the flow approaches the maximum rate as long as units are available in the rear. The flow becomes smaller as demand becomes smaller. If demand is negative, units then flow from front to rear and become available for flow to fronts with positive demand.

Examination of Figure IV-2 for the form of the demand-response equations shows that they do meet the need to be simple, symmetrical, decomposable and scalable. As in the r and X equations, decomposition is accomplished by programming such that each term in the demand-response equations is computed separately in the model and added to obtain demand or response. Thus, the contribution of each component is always produced as output along with the total demand and response.

B. ROLE OF THE HEURISTIC FORMULATIONS

The heuristic formulations are logical and meet the stated design tenets, but they cannot be proved to be rigorously correct. They are necessary elements of the model, however, in that they tie all the forces, attritions, and expenditures together into movements. One may wonder what to make of the fact that we can't do without them, but we

$$\text{DEMAND FOR REINFORCEMENTS IN FRONT} = [\text{SCALE FACTOR}][\text{ALLOWABLE DENSITY} - \text{PRESENT DENSITY}][\text{COMMANDED ADVANCE RATE} - \text{ACTUAL ADVANCE RATE}] + \text{REPLACEMENT OF LOSSES}$$

FRONTS 2 & 3 ARE COMMANDED TO ADVANCE AT A FRACTION OF THE RATE OF ADVANCE OF FRONT 1

$$\text{FLOW OF REINFORCEMENT TO/FROM FRONT} = [\text{MAX FLOW RATE PER UNIT}][\text{UNITS AVAILABLE IN RESERVE}]\left[1 - e^{\frac{-\text{DEMAND}}{\text{MAX RATE} \cdot \text{UNITS AVAILABLE}}}\right] \quad \text{FOR } D > 0$$

$$= [\text{MAX FLOW RATE PER UNIT}][\text{UNITS IN FRONT}][\text{DEMAND}] \quad \text{FOR } D < 0$$

Figure IV-2. Form of Demand/Response Equations

27

can't be sure they are correct either. The answer is that we must try to use the model to get insights that are independent of the exact values and forms of the heuristic formulations. This means for example that we must not use the model to predict actual FEBA position, but one can use it to compare FEBA positions under conditions of various force mixes, allocations, etc. Likewise we cannot use the model to predict when specific supplies will exhaust, but we can use it to learn that supply scarcity may be a problem, and estimate the time period in the conflict when supplies will become a factor.

In other words, results related to movements can be used to discover trends and driving interactions, but the heuristic formulations cannot be used to predict precise real world outcomes.

One of the uses of the model that is relatively independent of the heuristic formulations is that for which it was originally written: to evaluate the time histories of the attritions of all the systems due to all causes. The equations that describe the attrition processes are not heuristic, but are rigorously correct mass conservation equations which hold unequivocally. These equations are described below.

C. RESOURCE COUPLING AND ATTRITION/CONSERVATION EQUATIONS

In COMBAT II, resources generally are located in four places for Red and for Blue. They are the three fronts and the rear area. Strict accounting, as a function of time, is kept of the amount of each resource in each location. This amount changes with time for two reasons, a) flow into or out of the location and b) attrition in the location. There are usually several components to the total attrition rate. Strict accounting is kept of each component attrition rate and the flow rate and their integrals. This is what is meant by conservation. A quantitative account can be given at any time of all the causes contributing to the change in resource amount in any location.

These points and the coupling aspects are illustrated by the two differential equations shown in Figure IV-3.

These two equations are for the number of ground units in one front and the number of aircraft. The first equation shows a flow term and five component attrition terms. No flow term appears in the second equation since

TIME RATE OF CHANGE OF GROUND UNITS IN FRONT 1 = FLOW FROM REAR TO FRONT − LOSS RATE DUE TO GROUND UNITS − LOSS RATE DUE TO NUC ARTY − LOSS RATE DUE TO NUC MSLS − LOSS RATE DUE TO CENTRAL MISSILES − LOSS RATE DUE TO AIR

TIME RATE OF CHANGE OF AIRCRAFT = − LOSSES TO INTERCEPTORS − LOSSES TO AREA AIR DEFENSE, ALL TARGETS − LOSSES TO POINT AIR DEFENSE, ALL TARGETS − LOSSES TO CENTRAL MISSILES − LOSSES TO AIR ATTACKS ON BASES

Figure IV-3. Forms of Resource Coupling Equations

aircraft are always centrally based. They operate in the fronts and in the rear but are never frontally based.

Resource coupling is illustrated by these two equations in that part of the attrition of ground forces is due to enemy air (first equation). The loss rate due to enemy air however is proportional to the number of enemy air, which involves the second equation. In the second equation however part of the attrition of enemy air is due to area air defense. This attrition is proportional to the amount of area air defense which is proportional to the number of ground units (first equation).

This type of coupling exists throughout the entire set of resource rate equations.

D. LEVEL OF AGGREGATION

Ground forces in the field will normally consist of a large number of different elements such as tanks, APC's, trucks, tube artillery, antitank weapons, air defense weapons including missiles, fixed and rotary wing aircraft, communications, surface-to-surface missile systems, personnel, and supplies of ammunition, POL, etc.

In COMBAT II the basic ground unit is the combined arms company. The basic ground unit has a capability and vulnerability appropriate to the combination of tanks, APC's, air defense systems, personnel, and supplies that it represents. Conventional tube artillery, and antitank weapons are aggregated with the combined arms company. Army aviation is not played. Communications links and nodes are not explicitly defined. They are assumed to exist however, and parameters that consider their effects are included.

All the supplies of various kinds needed to support a ground unit are similarly aggregated into an entity called a supply packet. The basic packet is three days' supply for company or regiment. Supply packets are consumed, and are attrited either with their associated ground units or as separate targets.

Entities (in addition to the aggregate quantities discussed above) which are explicitly played with account being taken of their numbers, capabilities and vulnerabilities are:

- nuclear artillery rounds
- short and long range missile launchers
- short and long range missile rounds
- three types of aircraft
- nuclear weapons for the aircraft.

Spatial localization of entities in COMBAT II is no more fine grained than the specification of a particular front or the rear area. COMBAT II deals with the number of entities of various kinds that exist as a function of time on both sides in the fronts or rear areas. It does not follow each or any individual unit through an engagement and develop its history nor does it keep track of the specific location of a unit in the front or rear.

Figure IV-4 helps understand the level of aggregation. This is again the conservation equation for ground force packets in Front 1 as shown earlier, except that two of the terms in the equation are expanded to show their components. The time rate of change term on the left of the equal sign relates to the number of battalions or regiments respectively in the front. Each battalion is made up of three combined arms company packets. Each regiment is made up of ten combined arms packets. The company packets are targeted and attrited, but the variable kept track of is the number of battalions or regiments.

The flow of battalions or regiments is defined in terms of the demand-response equations defined earlier. A number of parameters describe the properties of the demand-response system. Note that the demand-response system is coupled to the entire problem. This is one reason hand calculations of this type problem are not feasible, and why manual war games get bogged down. There are too many loops to trace manually.

The third term expanded shows how the frontal nuclear missiles couple into the ground unit equations. The missile flow is described in terms of a number of variables, and is also highly coupled to the other systems.

Thus, it can be seen that while COMBAT II is relatively highly aggregated it also keeps track of various processes that go on in the system. This approach is consistent with the rule of detail given in Chapter III.

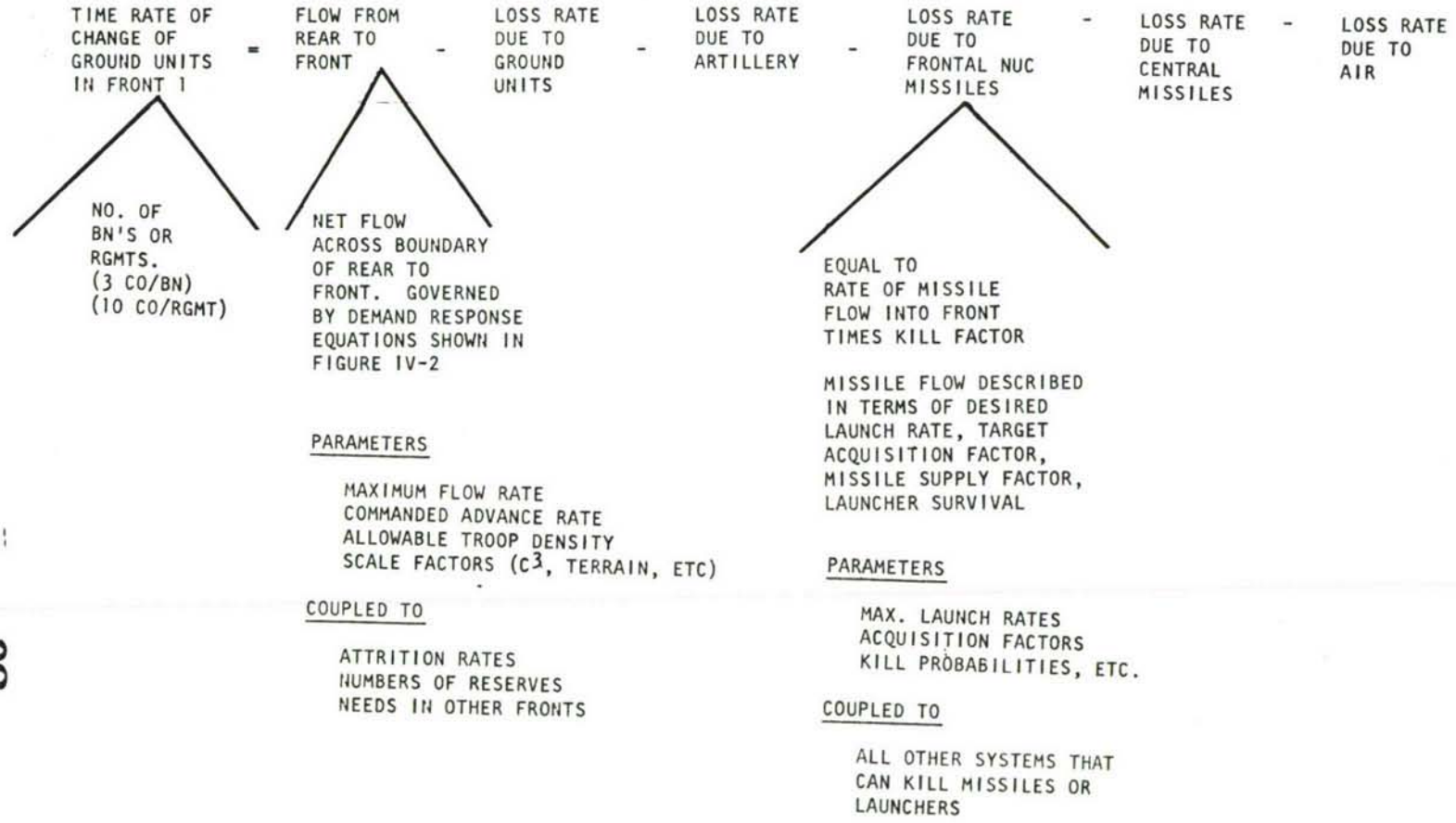


Figure IV-4. Expanded Terms of Ground Unit Conservation Equation

The model is intended to be exercised to explore the sensitivity of the outcome to the values taken by the process parameters and variables.

CHAPTER V

STRENGTHS AND LIMITATIONS OF COMBAT II

A. CURRENT LIMITATIONS

- Only manual input strategies are played. Logical decision rules are needed.
- Provision is not made to distinguish NATO force composition differences nor asymmetries in the combat capabilities of opposing forces at each front. In other words, one parametric value or capability measure usually applies to the entire theater, rather than defining these by front.
- Provision is not made to represent multiple classes of tactical nuclear and non-nuclear weapons employed at Division and Corps level.
- The effects of delayed casualties and contaminated areas due to nuclear detonations are not played.
- Collateral damage is not considered.
- Rear area logistic nets are not explicitly defined.
- Direct attack on C^3 with resultant effect on the timeliness and adequacy of information is not played. The existence of C^3 is implicit.
- Target acquisition is treated very simplistically. It assumes that target acquisition probability depends in a rather arbitrary way on only the number of targets still available.
- Terrain, weather, day and night effects on target acquisition and movement rates are not played explicitly. Provisions are made for accounting for these effects by manual inputs.
- COMBAT II provides for FEBA movement on three fronts but has no provision to represent breakthrough, overrun, encirclement and capture.
- Judgmental factors such as effect of surprise on troop morale, psychological effects of nuclear weapons, morale and discipline are not now included. Provisions are made for inclusion of judgmental factors if estimates of their values become available.

B. STRENGTHS OF COMBAT II

- COMBAT II takes an integrated approach to a two-sided, mixed conventional and nuclear conflict involving simultaneous interactions among ground, missile, and air forces at the theater level.
- The extreme transparency of the model enables the analyst to understand exactly why things happened as they did in a given case.
- Time histories of over 1000 individual types of combat interactions are calculated in the model and available to the analyst. This makes it possible to decompose any effect with respect to its contributing causes.
- COMBAT II is exceptionally user oriented with regard to ease of data input and set-up. A completely new problem requires about three man days to set-up. A minor excursion on an existing problem as little as a half hour.
- The model is very fast running. Typical run times for a ten day war are less than two minutes on a CDC 7600.

These last two points encourage analyst use of the model to gain insights into tradeoffs, sensitivities, etc.

As much of the power of COMBAT II is related to its transparency, it is important for the reader to understand why the model is transparent. Figure V-1 shows several FORTRAN IV lines from the main subroutine, ATTRIT. The equation on line 495 is the ground force conservation equation shown in Figure IV-4, except that the flows have not yet been added in. Note that no numbers occur explicitly in the equation. Every term is written as a subscripted variable. For example, A0403P is the missile attrition term described in Figure IV-4. This term is described elsewhere in terms of other subscripted variables. There are no numbers hard wired with the code. All the values of all the factors, terms, and variables are maintained as functions of time and output on magnetic tape. That way the history of each and every calculation performed within the model is available to the analyst. That is complete transparency.

```
C*****************************************************************************  ATTRIT    490
C     FIFTH EQUATION SET                                                        ATTRIT    491
C     FLOWS AND ASSOCIATED ATTRITION                                            ATTRIT    492
      DO 5480 I=1,IF                                                            ATTRIT    493
C                                                                               ATTRIT    494
C     G1 ATTRITION                                                              ATTRIT    495
C EQN (5-1) - TOTAL G1F(I) ATTRITION                                            ATTRIT    496
      A0501P(I,IB)= A0301P(1,I,IB)+A0301P(2,I,IB)                               ATTRIT    497
     1+A0321P(1,I,IB)+A0321P(2,I,IB)+A0321P(3,I,IB)+A0401P(I,IB)                ATTRIT    498
     2+A0402P(I,IB)+A0403P(I,IB)                                                ATTRIT    499
 5480 CONTINUE                                                                  ATTRIT    500
      DO 5500 J=1,JA                                                            ATTRIT    501
```


Figure V-1. Example of COMBAT II Code

CHAPTER VI

PROPER AND IMPROPER USES OF COMBAT II

This chapter is intended to help the user know when and how to use the model and what mistakes to avoid.

A. PROPER USES

- The model is designed to be a vehicle for giving an overview of the theater level mixed combat exchanges.
  - Attrition of each system can be analyzed by cause
  - Sensitivities to supply and reinforcement quantities and rates can be identified
- The model can be used to explore the rate of expenditure of high value (including nuclear) systems.
  - Sensitivities to acquisition factors, launch rates, kill factors can be examined
- Sensitivities to mobilization times can be determined.
- Impacts of variations in release times can be analyzed.
- Significance of alterations in target allocation rules and strategies of weapons employment can be studied.
- Sufficiency of the stockpiles can be explored.
  - Distribution of the stockpile weapons among the various Blue and Red sectors can be evaluated in terms of impact on the theater level outcome.
- MBFR trades among the various force components can be studied.
- Some estimates and bounds can be put on the relative overall force balance in Europe.
- Potential payoffs for new or proposed systems can be examined.
  - What sorts of weapons will make a difference in outcome?
- Impacts of various tactical air bed down and dispersion places can be assessed.
- In general the model can be used to learn what is driving the outcome and to determine where to develop additional detail. COMBAT

II is a wide-angle magnifying glass that lets us see the entire problem in perspective and tells us where to focus our microscopes.

B. IMPROPER USES

- The worst mistake that could be made, using COMBAT II, would be to interpret the results as precisely accurate predictions. Trends yes - point values no. In other words the model must not supplant judgement. To repeat an earlier statement: "The model does the work, we must do the thinking."
- COMBAT II cannot be used to obtain Corps, Division or Battalion level detail. Frontal and theater level aggregation is maintained. (However, the modeling concepts in COMBAT II can be extended to Corps and Division/Brigade level detail in new models which will be discussed in Chapter VIII).
- Detailed studies of the central logistics net are impossible. The impact of supply stockpiles and flow rates can be assessed, but the details of the LOC's are not available.
- Comparison of NATO to U.S. capabilities is not practical with COMBAT II, nor is differentiation among various national components of the PACT system. This is because a quantity such as the acquition factor is the same for all three fronts of Red or Blue.
- Only one type of nuclear artillery is included. This means that high resolution of the contribution that each type of nuclear artillery makes to the outcome is not available. However, the aggregate effect of all the types of artillery is available.
- Effects of collateral damage limiting constraints cannot be assessed nor is the amount of collateral damage created calculated in the present version of COMBAT II. The latter will be included in later developments.
- Effects of delayed casualties are not known. This will be rectified later.
- Aggregate values are used for the measure of conventional ground-to-ground attrition. Conventional attrition among the combined

arms ground units cannot be obtained on a weapons system by weapons system basis. Recent runs of the model have shown that conventional artillery should be specifically broken out. (This is an example of the model being used as intended; to learn where additional detail is required).

CHAPTER VII
CONTINUING DEVELOPMENT OF COMBAT II

Research with COMBAT II is proceeding along three general lines: specific issues of current interest to force planners are being studied from theater level perspective; the model itself is being strengthened through addition of new features, additional detail and improved submodels; the model is being used as a pilot for the development of an operational family of hierarchical models from engineering detail to theater level.

Specific studies will not be discussed because of security considerations. The role of COMBAT II in the development of a hierarchy of models is described in Chapter VIII. Development of improvements to COMBAT II are discussed briefly below.

A series of developments and improvements are planned. Two projects are in progress. One is to evaluate the utility and savings in computer time of a faster but less accurate method for integrating the hundreds of differential equations in COMBAT II. The second ongoing project is to develop an economical systematic methodology for calculating the time histories of the sensitivity of results to the more than 1000 variables in the model. An approach to the sensitivity analysis has been developed. Testing and implementation will be initiated when the integrator is finalized.

The next major step planned is the development and implementation of a family of logical allocation rules for air and missiles. Target selection strategies for these high value resources dominate the outcome of the theater level engagement. While capability for user input target selection strategies must and will be maintained, there are many applications of interest where it is desirable to adjust strategies automatically to account for changes in force posture on quality.

Several other needed developments have been identified by exercising the model on problems of interest. An important planned development is to include an account of casualty assessment. Other developments needed

include provisions for specific treatment of several additional types of frontally controlled weapons systems.

Other developments are suggested by the weaknesses listed in Chapter V. Revisions that compensate for some of these weaknesses may be included in COMBAT II, but many would better be built into other models of the hierarchy described in Chapter VIII.

CHAPTER VIII

CONCEPT OF AN INTEGRATED COMBAT ASSESSMENT (ICA)

A. RECAP OF PREVIOUS CHAPTERS

This section reviews the fundamental problems with military modeling, identifies the role of COMBAT II as a solution to some of the problems, and highlights the problems remaining.

1. Fundamental Problems

Chapter II identified the fundamental military modeling problems of complexity, level of detail, lack of physical theory, and non-linearity.

2. Role of COMBAT II

The primary function of COMBAT II is to address the level-of-detail problem by determining what details need to be known. The transparency features of the model allow the analyst and user to deal effectively with the complexity of the problem. Heuristic formulations that meet the discipline described in Chapter III deal adequately with the lack of physical theory. All these features of COMBAT II serve as an example for new model developments.

3. Problems Remaining

Two major problem areas remain. First, the design of COMBAT II as a vehicle for learning what details are important precludes putting high resolution into the model. In other words, COMBAT II can say what detail is important, but it cannot develop that detail. Other models are required for this. A review of the limitations of the model listed in Chapter V, along with the planned developments noted in Chapter VII, indicates that all the limitations of COMBAT II that are not scheduled for improvement fall into the category of additional detail. We do plan to work these problems with appropriate models however.

The second major problem area remaining is non-linearity. Recalling from Chapter II, this problem is caused by the fact that all the levels in the modeling hierarchy are highly interdependent. The theater level assessments depend on kill factors and acquisition probabilities that depend on

unit engagements which in turn depend on the numbers of forces involved, but the numbers involved depend on theater level resource allocations - and so on and so on. The COMBAT II model does not work the non-linearity problem. That methodology is called the BDM Integrated Combat Assessment methodology (BDM-ICA), and is described below.

B. CONCEPT OF THE BDM-ICA METHODOLOGY

Figure VIII-1 shows the hierarchy of basic models in the ICA methodology. The methodology is designed to do two things: meet the level-of-detail tenet and solve the non-linearity problem. The models in the hierarchy contribute as follows:

1. COMBAT II

COMBAT II is the overall pilot model where the wide angle lens is swept over the entire theater, and over the entire time period of the conflict. This is primarily to determine the time histories of the driving processes and variables.

2. T-COR Model

The T-COR model is also a theater level model, but with at least 8 separate Corps regions on each side (or Combined Arms Army regions as appropriate). Many details determined by COMBAT II runs to be important will be included in T-COR. Examples include resolution of Blue and Red force composition differences by Corps or Combined Arms Army Areas; specification of conventional and nuclear artillery by type and nationality; resolution of C^3, EW and target acquisition factors at Corps/CAA level; and consideration of additional aircraft types.

Because of the additional detail, T-COR will have ten times as many variables as COMBAT II. Consequently T-COR will require somewhat longer computer running times than is now required for COMBAT II. This will be much less than a factor of ten however, because a faster integrator is planned for both models.

In any case, T-COR will be slower to run and set up than COMBAT II because that is the price of detail. However, it should not be necessary to run T-COR for the entire length of the campaign. COMBAT II runs show at what time a system becomes critical. T-COR can then be run and

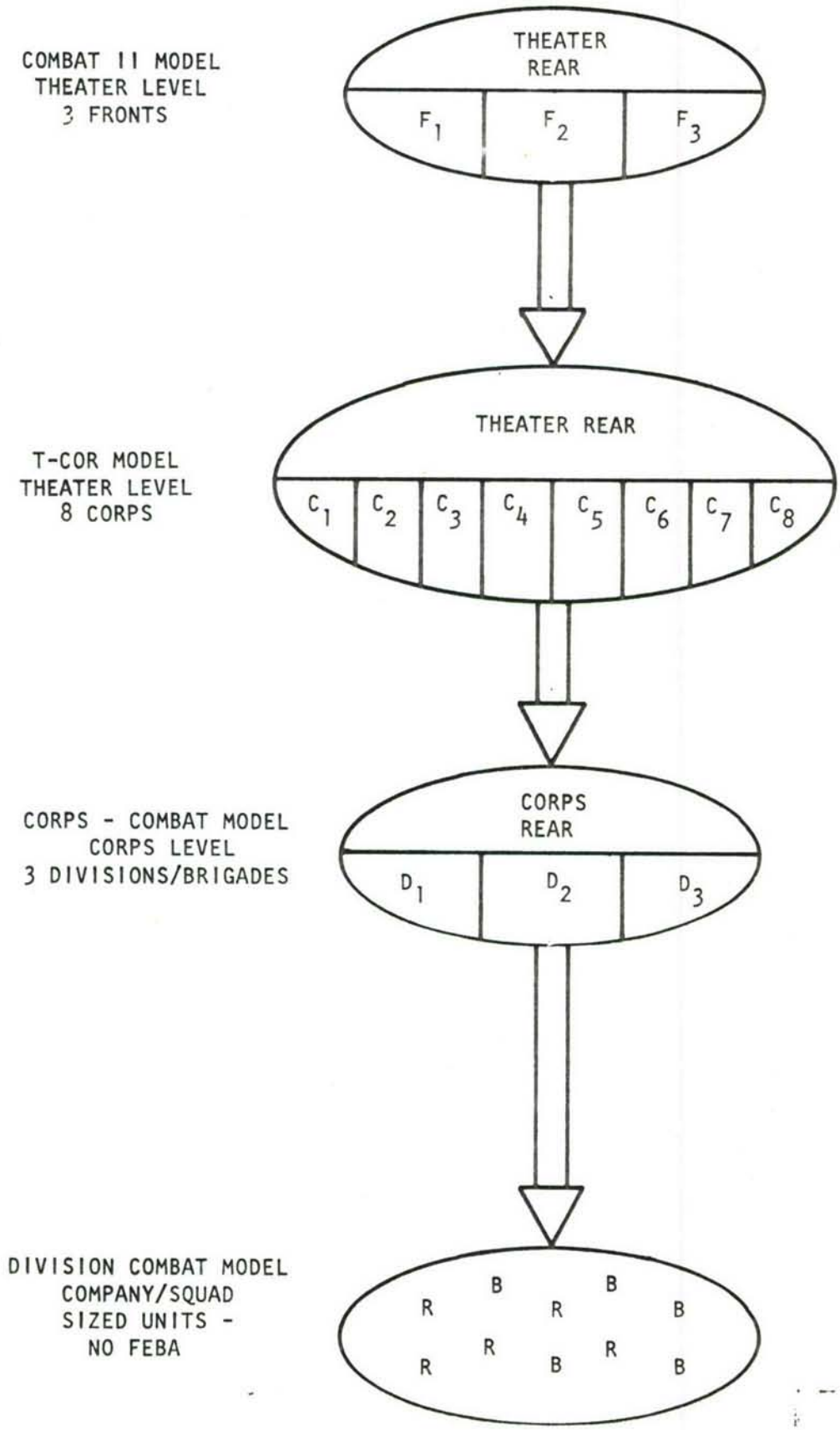


Figure VIII-1. BDM-Integrated Combat Assessment Methodology

should be operated only during this time to obtain details shown by COMBAT II to be important.

3. CORPS-COMBAT Model

The next model in the hierarchy is the CORPS-COMBAT model. This is a model much like COMBAT II, but scaled to CORPS rather than theater level. Where COMBAT II has three fronts that may be 100 km wide, CORPS-COMBAT has three Division/Brigade combat zones which are only a few kilometers wide. Thus breakthrough zones can be readily identified.

CORPS-COMBAT is designed to be used with T-COR and operated during vital periods of the conflict. Hence, T-COR would specify the resources flowing to each corps as a function of time. This includes tactical air sorties, centrally controlled missile exchanges, reinforcements, supplies, etc. Knowing the resource flow into the CORPS, the CORPS-COMBAT model would then be used to model the combat down to Division/Brigade levels. As noted above, breakthroughs can be readily studied.

The CORPS-COMBAT model is also the basic structure upon which to superimpose details of the corps level integrated air-ground C^3 and target acquisition systems. These systems comprise networks that are overlayed on the ground battle structure and their function and disruption impact the outcome of the battles at the Division/Brigade fronts in two ways. First, the C^3 system controls the resources allocated to the Division/Brigade fronts, and more importantly, controls the massing of these resources. Massing of artillery lines and employment of close air support are examples. Secondly, the C^3/TA system fundamentally determines the effectiveness of the ground/air forces by either finding or not finding targets.

Once the basic C^3/TA systems are integrated into the CORPS-COMBAT model, it will be possible for the first time to quantitatively assess the impact of EW systems on combat capability. This will be accomplished by first developing measures of the twin EW missions of enhancing friendly target acquisition capability and disrupting enemy C^3 and target acquisition capabilities. Then through use of the CORPS-COMBAT model the impact of EW perturbed target acquisition and C^3 systems on the outcome of the battle will be assessed.

4. Division COMBAT Model

The Division COMBAT Model is the lowest level in the hierarchy shown because most of the models below this level are at a reasonably good state of development compared to the Division level.

The Division COMBAT Model is fundamentally different from the models above. COMBAT II, T-COR and CORPS-COMBAT are essentially resource allocation models which keep track of force units as they cross certain boundaries (fronts, corps, or Division/Brigades), but these models do not keep track of the specific location of each resource once it crosses a boundary. In other words, these three models put the resources in bins, so to speak, and keep track of the flows in and out of the bins, and the losses due to attrition inside the bins.

But the "bin model" does not give sufficient resolution at Division level because at this level spatial relationships must be described between each set of firing weapons and targets. This means that the locational coordinate of each ground unit must be maintained in the model. When the many important types of weapons systems are considered, (such as tanks, APC's, anti tank weapons, troops, artillery, several types of tactical aircraft and helicopters, etc.) the models tend to be large and complex.

We are developing concepts for a fast running, easy to use division combat model, but this is beyond the scope of this paper. Although a better model is needed there are now in existence a number of models that can operate at this level reasonably well until the better model comes along. Two of these are DIVOPS and DIVWAG. With some modifications for Tac Air and Air Defense, either of these can be used to solve the modeling hierarchy. An open loop and a closed loop method are described below.

C. TWO METHODS FOR SOLVING THE MODELING HIERARCHY

The first attempt at a solution should be open loop. This would proceed as follows:

- Develop inputs to COMBAT II based on qualitative understanding of the problem and quantitative use of submodels for scenarios that are expected to be typical of the conflict.

- Operate COMBAT II with these values and determine the outcome and the sensitivity of the outcome to the inputs. Determine the critical time period in the conflict.
- Operate T-COR for the critical time period only. Determine the outcome, and the resource flows/attacks into each corps and corps rear area.
- Using the resource flows/attacks into the corps, operate the CORPS-COMBAT model to determine resource flows/attacks into each Division/ Brigade sector.
- Using the resource flows/attacks in the Division/Brigade sector operate DIVOPS or DIVWAG or the BDM Division COMBAT model to determine interaction factors such as kill probabilities, etc.
- Compare the factors developed at division level to those used in the models above.
- If the values are within the sensitivity bounds developed in step 2, the problem is solved. Otherwise, using the sensitivity analysis results, estimate the outcome due to the new interaction variables.

This concludes the open loop approach. This method develops detail where and when it is needed, but does not go into details that are not drivers. Furthermore, by operating the higher level models first, the set up scenarios for the highly detailed models, such as DIVWAG, are provided with meaningful numbers of resources. This avoids the problem of estimating out of context such things as the number of close air support sorties available to support a particular division.

The open loop appraoch also allows a check on the sensitivity of DIVWAG type results. Variations around the DIVWAG factors can be played with in all of the higher level models.

The open loop approach has the disadvantage that convergence is not required of the interaction values used in COMBAT II or T-COR with the interaction values calculated at division level. The converging case is the closed loop method.

The closed loop method is similar to the open loop except, if the Division level calculated values differ from the assumed values used at

theater level, the calculated values are input at theater level and the entire process is repeated until convergence occurs.

Obviously the closed loop approach could be time consuming. The utility of the closed loop method depends on the speed of the Division level model and the integration of the programming of all the models with a single chained code with an executive processor. DIVWAG and DIVOPS are unsatisfactory for this application. The concepts of the BDM Division COMBAT model are being developed with this application in mind. This will be the subject of a subsequent paper.

D. RECAP OF ICA

To recapitulate, the Integrated Combat Assessment methodology described above is a concept for solving the military modeling hierarchy in a consistent and disciplined manner that provides some confidence, at least, that relevant detail is preserved. The pilot model, COMBAT II is operational, and T-COR and CORPS-COMBAT pose no major technical difficulties. Division models such as DIVWAG and DIVOPS are available so that once T-COR and CORPS-COMBAT are developed the hierarchy can be solved using the open loop method. The closed loop solution requires a modeling breakthrough at division level.

THE BDM CORPORATION

1920 Aline Avenue
Vienna, Virginia 22180
Phone (703) 893-0750

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CV

COMBAT II
A METHODOLOGY FOR ANALYSIS OF MIXED COMBINED ARMS COMBAT AT THEATER LEVEL

This effort supported by the Defense Nuclear Agency under:
NWED Subtask Code P99QAXDD030 Work Unit Code 11

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FOREWORD

COMBAT II is a computerized methodology for calculating detailed time histories of over 1,000 individual combat interactions among mixed conventional and nuclear forces. Time histories for combat systems include the number of remaining units at various locations, targets of every type killed within the system, supply flows, deployments, and attritions due to each enemy source. These histories are derived by integrating a coupled set of differential equations for each opponent. COMBAT II was designed to be as aggregate as possible while representing all relevant military interactions and the details of nuclear system effectiveness.

This briefing is intended to familiarize the reader with the COMBAT II methodology. It includes a general description of the model, discussion of the concepts involved and examples of how the model treats conventional conflict, a mixed conventional/tactical nuclear conflict and important sensitivities. A summary highlights implications for further research.

COMBAT II was developed under contract DNA001-74-C-0280 and the joint sponsorship of the Office of the Assistant to the Secretary of Defense (Atomic Energy) and the Defense Nuclear Agency. Additional support was provided by representatives of the Office of the Assistant Secretary of Defense (Intelligence). The model and results of a pilot study are documented in the Mixed Combat Theater War: Pilot Study (U), BDM/W-74-038-TR, September 1974, SECRET.

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SECTION I
DESCRIPTION OF COMBAT II

This section outlines the major systems and interactions modeled by COMBAT II. It precedes a discussion of important conceptual innovations incorporated in the model.

COMBAT II COMPONENT SYSTEMS

Systems considered in COMBAT II are ground force units (with a proportionate share of conventional artillery), nuclear artillery, tactical missiles, aircraft, supplies and nuclear warheads. Conventional and nuclear exchanges are permitted, and ground-to-ground duels, tactical missile exchanges and air battles occur. The air battle includes air-to-air engagements and attrition due to both area and terminal air defenses.

COMBAT II may be operated at division, corps or theater level. Runs to date have been at theater level with three separate fronts. A relationship for estimating FEBA movement of each front is assumed in terms of the numbers of ground force units and attrition rates of each side. This function serves primarily as an index of the position of each front and is calculated independently of the simultaneous differential equations for interactive attrition. Because of this independence, calculations of relative force draw-downs and the relative attrition of one system versus the other (air vs. missiles, for example) are independent of the specific form chosen for FEBA movement.

COMBAT II COMPONENT SYSTEMS

BATTLE SYSTEMS

- GROUND COMBAT
  - COMBINED ARMS UNITS (INFANTRY, ARMOR, ARTILLERY)
  - NUCLEAR ARTILLERY
  - FRONT CONTROLLED MISSILES
  - CENTRALLY CONTROLLED MISSILES (ALLOCATION)
- AIR-TO-AIR COMBAT
- AIR-TO-GROUND COMBAT
  - ALLOCATION OF AIR BATTLE SURVIVORS TO GROUND TARGETS
- AIR DEFENSE
  - AREA
  - TERMINAL

THREE FRONTS AND REAR ON EACH SIDE

- REAR SUSCEPTIBLE TO AIR AND CENTRALLY CONTROLLED MISSILE ATTACK

AIR BASES OF TWO TYPES

- WITHIN RANGE OF CENTRALLY CONTROLLED MISSILES
- BEYOND RANGE OF CENTRALLY CONTROLLED MISSILES

RESUPPLY AND REINFORCEMENT FLOWS

The model plays three fronts within which each side has Force Packets (G1), Supply Packets (G2), Nuclear Artillery (G3) and its warheads (G5) and Frontal Surface-To-Surface Missile (SSM) Launchers (G4) and their warheads (G6). The representative array illustrates by means of arrows the current allocation of forces and weapons to targets in the fronts. Fires are exchanged only with the opposing front and only the SSM can attack any target in the front. Force Packets attack only Force Packets and Nuclear Artillery is limited by range to attacking Force Packets only.

In the rear are Reserve Force Packets (G1R), Resupply (G2R), Nuclear Storage Sites (S), Air Bases (B1 and B2) and centrally controlled SSM Launchers (L1) with their warheads (M1). The model has the capability to play an additional SSM Launcher (L2) with its warheads (M2) but this capability has not been used. The Airbases are divided into two categories: B1 bases are those within range of the opposing centrally allocated SSM's and B2 bases are beyond this range.

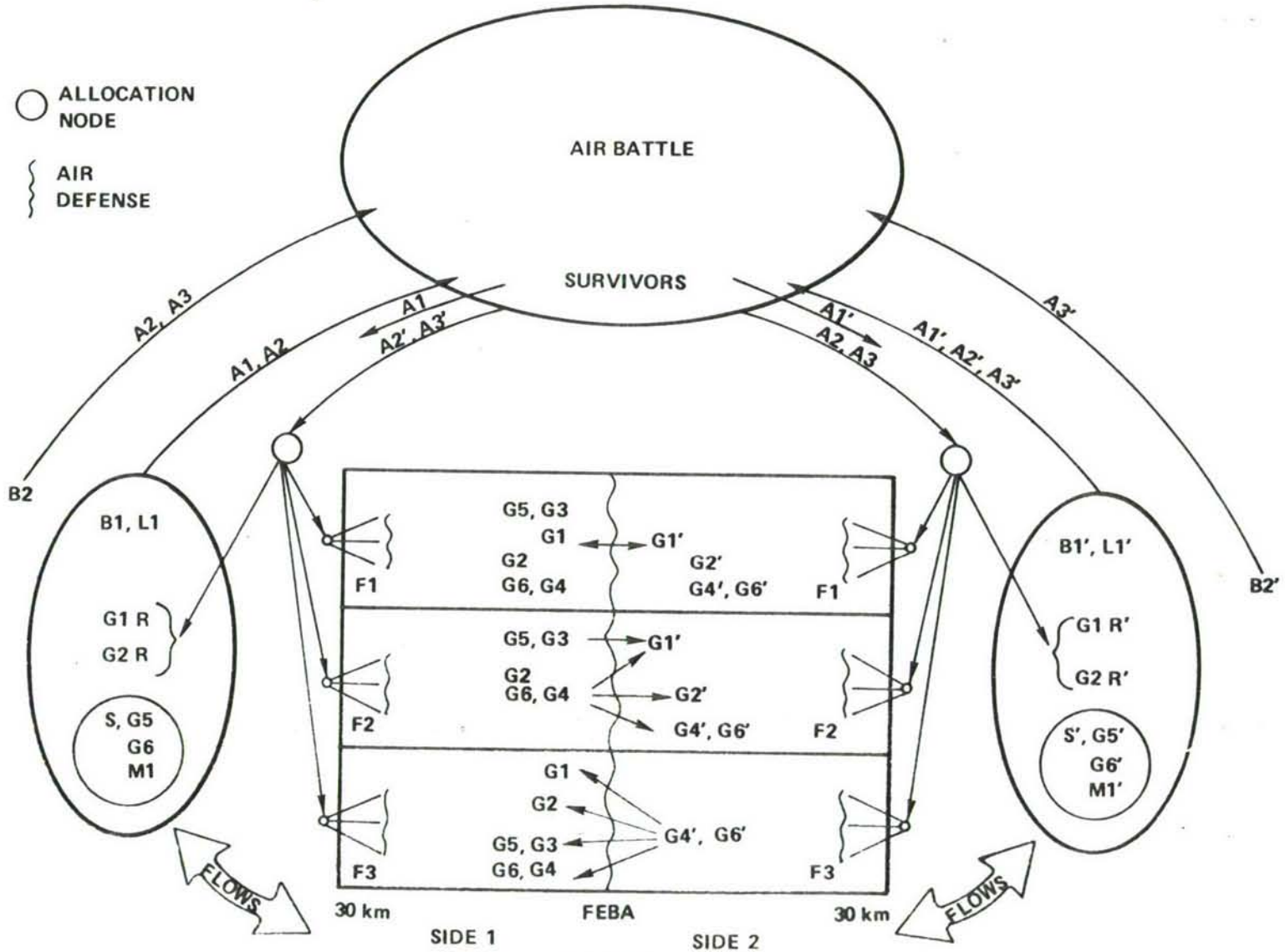
Aircraft are divided into three nominal types. A1 aircraft are interceptors which engage enemy aircraft and return to bases. These could be allocated also to ground support roles but only using conventional ordnance. A2 aircraft are nuclear capable and are used in a ground support role as are A3 aircraft, with the latter being long range aircraft.

Both the ground support aircraft and SSM's in the rear are allocated to targets by inputs prior to running the code. The code does have the capability to allow reallocation during operation, but the changes must be input prior to running.

Flows occur from rear to front and from front to rear. Reinforcements and resupply flow from rear to front. However, resources can be moved from one front to another by being withdrawn to the rear and allocated to another front.

Aircraft types A2 and A3 which survive the air battle continue to attack targets for which they are allocated. They are subjected to both point and area air defense in these attacks.

COMBAT II MODEL INTERACTIONS



SECTION II
CONCEPTUAL FUNDAMENTALS

There are four conceptual elements which are fundamental to the architecture of COMBAT II. These are:

1) An Extension of Lanchester Theory,
2) A FEBA Movement Equation,
3) Demand--Response Equations, and
4) Resource Coupling Equations.

These concepts are discussed in this section before going on to example products.

EXTENSION OF LANCHESTER THEORY

For conventional direct fire and artillery exchanges between ground force units, a Lanchester Square Law is assumed. This gives a measure of relative conventional capability of a αB^2 and λR^2 respectively. The relative capability can be expressed by a dimensionless parameter, r.

The classical Lanchester theory is extended by assuming that αR and λR in the expression for r may be replaced by $-\dot{R}$ and $-\dot{B}$ respectively, and that these terms represent total attrition of ground forces due to all causes, not just conventional direct fire and artillery. Thus r is defined in COMBAT II as:

$$r = \frac{B\delta R - R\delta B,}{B\delta R + R\delta B}$$

where:

δR = Total Side I ground force attrition rate due to all causes (conventional and nuclear): δB is analogous for Side 2.

The dimensionless index r is used in an heuristic expression for FEBA movement rate.

EXTENSION OF LANCHESTER THEORY

LANCHESTER EQNS: $\dot{R} = -\alpha B \qquad \dot{B} = -\lambda R$

α = SIDE 1 KILLS PER UNIT TIME PER SIDE 2 UNIT

λ = SIDE 2 KILLS PER UNIT TIME PER SIDE 1 UNIT

COMBAT CAPABILITY: $\alpha B^2 \qquad \lambda R^2$

FRACTIONAL COMBAT CAPABILITY DIFFERENCE: $r \equiv \dfrac{\alpha B^2}{\alpha B^2 + \lambda R^2} - \dfrac{\lambda R^2}{\alpha B^2 + \lambda R^2}$

OR $r = \dfrac{B(\alpha B)}{B(\alpha B) + R(\lambda R)} - \dfrac{R(\lambda R)}{B(\alpha B) + R(\lambda R)} = \dfrac{B(-\dot{R})}{B(-\dot{R}) + R(-\dot{B})} - \dfrac{R(-\dot{B})}{B(-\dot{R}) + R(-\dot{B})}$

EXTENSION: CONSIDER $(-\dot{R})$, $(-\dot{B})$ AS TOTAL ATTRITION RATES OF SIDE 1 AND SIDE 2 GROUND FORCES DUE TO ALL CAUSES, NOT OPPOSING GROUND FORCES ONLY.

THUS: $r = \dfrac{B\delta R - R\delta B}{B\delta R + R\delta B}$, WHERE δR AND $\delta B \equiv$ TOTAL ATTRITION ON GROUND FORCES DUE TO ALL CAUSES.

FEBA MOVEMENT EQUATION

The primary purpose of COMBAT II is to calculate time-dependent attritions of the interacting combat systems throughout the theater. For tactical missile exchanges, most aircraft interactions, and ground force interactions over a period of a few hours, these attritions may be determined without considering ground unit movements. However, for larger periods of combat and for developing supply and reinforcement flows, it is desirable to include a function that specifies a rate of ground force advance as a function of the number and effectiveness of the forces on each side. There is no known set of physical laws that specify movement as a function of the combat elements involved. Consequently, any relationship between movement and forces must be largely heuristic. Even so, useful results are obtainable if the movement equation treats each side symmetrically.

The form chosen for COMBAT II is shown in the facing illustration. This equation has the property that for small values of r, corresponding to comparable capabilities, little FEBA movement occurs. For values of r approaching ± 1, corresponding to large capability disparities, the FEBA advances toward the weaker side. A limit is set according to terrain, weather, obstacle factors, etc. This limit may be varied with time.

DEMAND-RESPONSE EQUATIONS

The illustration shows typical demand and response equations as they exist in the model. In the demand equation there are three limiting factors. First, a maximum allowable density is input to the model as a policy decision. Thus, if the commander desires that his forces maintain nuclear density, this is input. Although the code allows this to be changed at any time-step, the change must be input prior to processing. The code then limits demand according to the maximum allowable density.

Another limiting factor is the difference between the actual and commanded advance rate with demand being greater, the greater the difference. Demand can be negative if the actual rate exceeds the commanded rate.

Finally, the scale factor allows input of the impact of mobility conditions--terrain, weather, etc.--into the model.

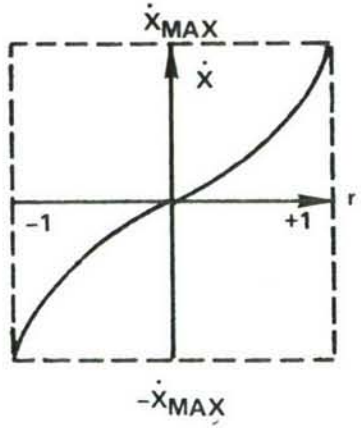
Flow equations which respond to demand depend on the maximum flow rate, an input to the code. When demand is positive and large, the flow approaches the maximum rate as long as units are available in the rear. The flow becomes smaller as demand becomes smaller. If demand is negative, units then flow from front to rear and become available for flow to fronts with positive demand.

FORM OF FEBA MOVEMENT EQUATION

FEBA MOVEMENT RATE = $\dot{X}$

$$\dot{X} = \dot{X}_{max} \left[.489r \quad + .511r^{5} \right]$$

GRAPHIC ILLUSTRATION OF FUNCTION



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FORM OF DEMAND-RESPONSE EQUATIONS

$$\text{DEMAND FOR REINFORCEMENTS IN FRONT} = \text{SCALE FACTOR} \left[\text{ALLOWABLE DENSITY} - \text{PRESENT DENSITY}\right] \left[\text{COMMANDED ADVANCE RATE} - \text{ACTUAL ADVANCE RATE}\right] + \text{REPLACEMENT OF LOSSES}$$

FRONTS 2 & 3 ARE COMMANDED TO ADVANCE AT A FRACTION OF THE RATE OF ADVANCE OF FRONT 1

$$\text{FLOW OF REINFORCEMENT TO/FROM FRONT} = \left[\text{MAX FLOW RATE PER UNIT}\right] \left[\text{UNITS AVAILABLE IN RESERVE}\right] \left[1 - e^{\frac{-\text{DEMAND}}{\text{MAX RATE} \cdot \text{UNITS AVAILABLE}}}\right] \quad \text{FOR } D > 0$$

$$= \left[\text{MAX FLOW RATE PER UNIT}\right] \left[\text{UNITS IN FRONT}\right] \left[\text{DEMAND}\right] \quad \text{FOR } D < 0$$

RESOURCE COUPLING EQUATIONS

Resources are coupled through differential equations of the form shown next. This allows the analyst to draw from the code the behavior of the rate of change over time and, through the integration of these equations, the value of the state variable over time.

The code calculates all values and integrals for each time step of the conflict being modeled. These are preserved on tape and an output processor graphically displays any variables selected by the analyst. This visibility of all calculations is one of the code's main features.

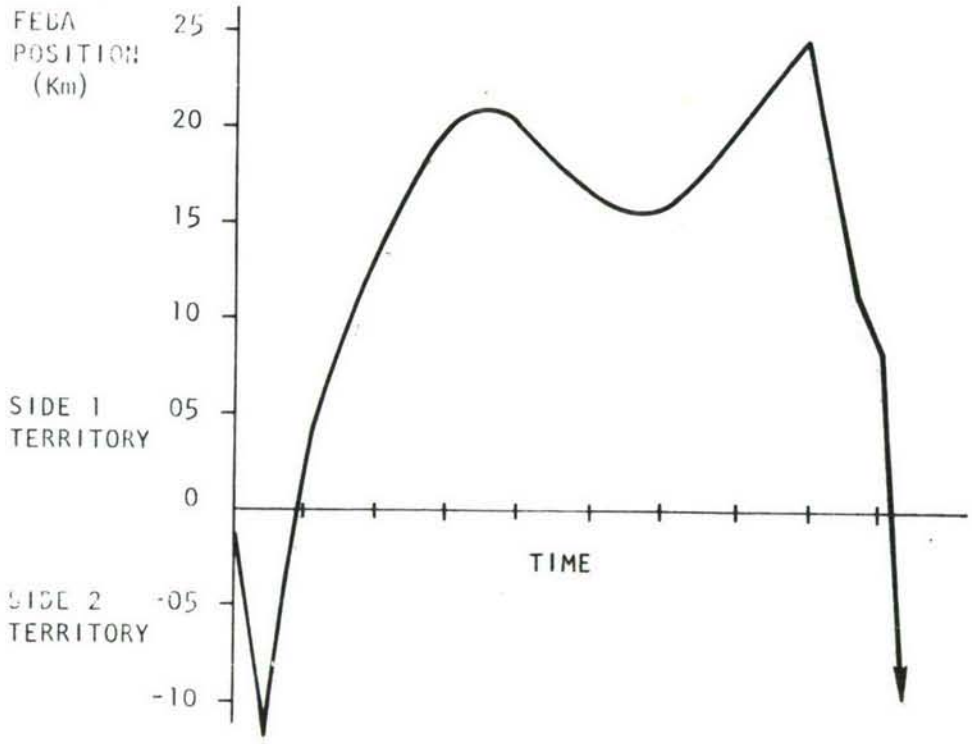
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DECOMPOSITION OF COMBAT CAPABILITY IN FRONT 1

The forces engaged on Front 1 are depicted here along with their relative effectiveness as measured by the rate of attrition caused on the opposing force.

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NUCLEAR CONFLICT FEBA POSITION ON FRONT 1 VS. TIME



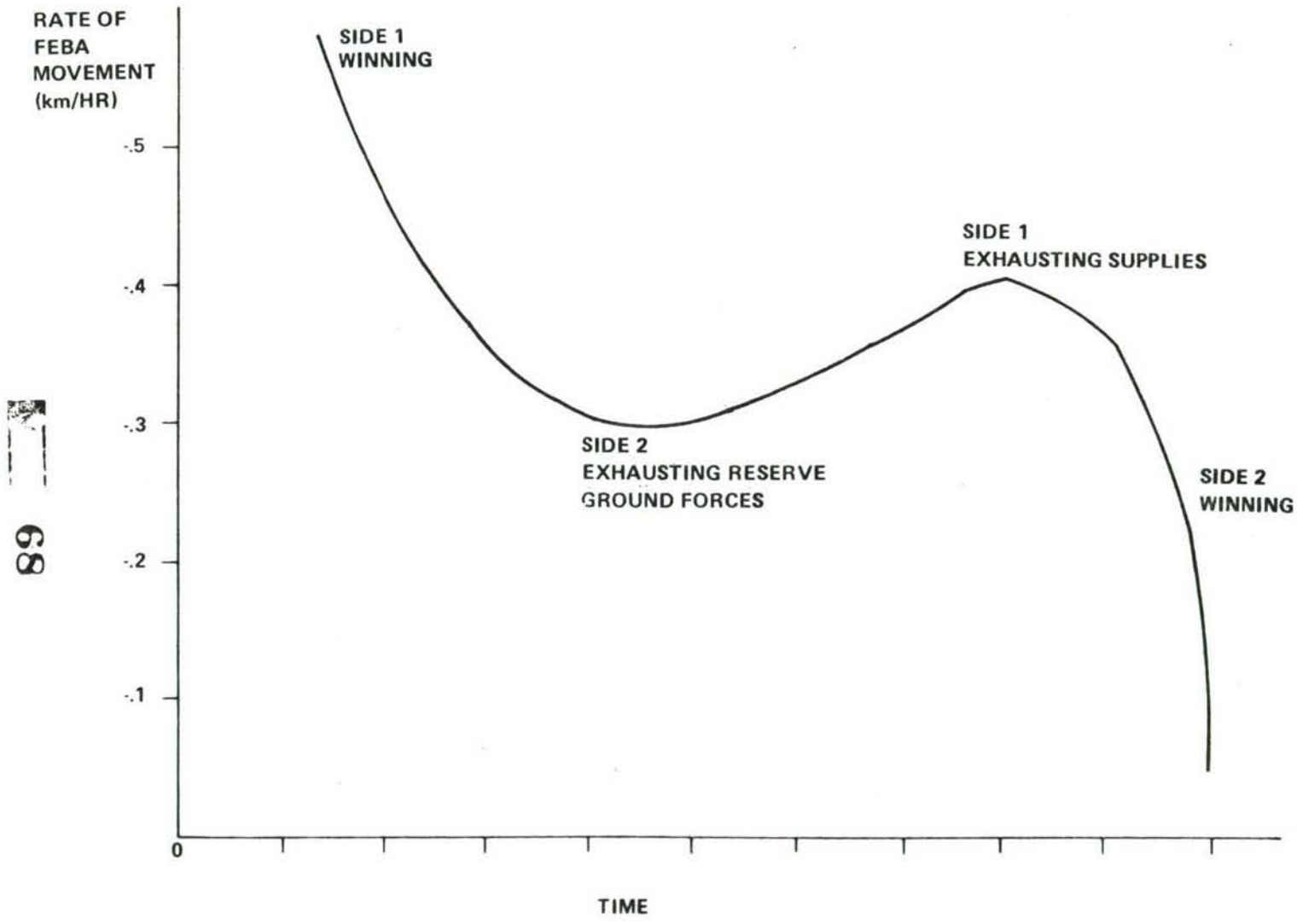
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GROUND FORCE DEPLOYMENTS

A display of ground force deployments further details the resource and deployment constraints modeled in the conventional conflict. It shows the rapid redeployment of Side 2 forces to Front 1 and the effect of attrition and replacement on the limited Side 2 reserves. Side 1 also suffers heavy attrition during early stages of the conflict. Side 2 maintains high reserves because it is prohibited from dense formations susceptible to nuclear attack and, in later stages, its supplies and rate of supply movement limits the number of units that can be sustained in combat.

It should be noted that the absolute number of units is not an accurate measure of combat capability. Side 1 ground force units are larger and relatively stronger than comparable Side 2 ground force units.

RATE OF FEBA MOVEMENT FRONT 1



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FORMS OF RESOURCE COUPLING EQUATIONS

TIME RATE OF CHANGE OF GROUND UNITS IN FRONT 1 = FLOW FROM REAR TO FRONT − LOSS RATE DUE TO GROUND UNITS − LOSS RATE DUE TO NUC ARTY − LOSS RATE DUE TO NUC MSLS − LOSS RATE DUE TO CENTRAL MISSILES − LOSS RATE DUE TO AIR

TIME RATE OF CHANGE OF AIRCRAFT = − LOSSES TO INTERCEPTORS − LOSSES TO AREA AIR DEFENSE, ALL TARGETS − LOSSES TO POINT AIR DEFENSE, ALL TARGETS − LOSSES TO CENTRAL MISSILES − LOSSES TO AIR ATTACKS ON BASES

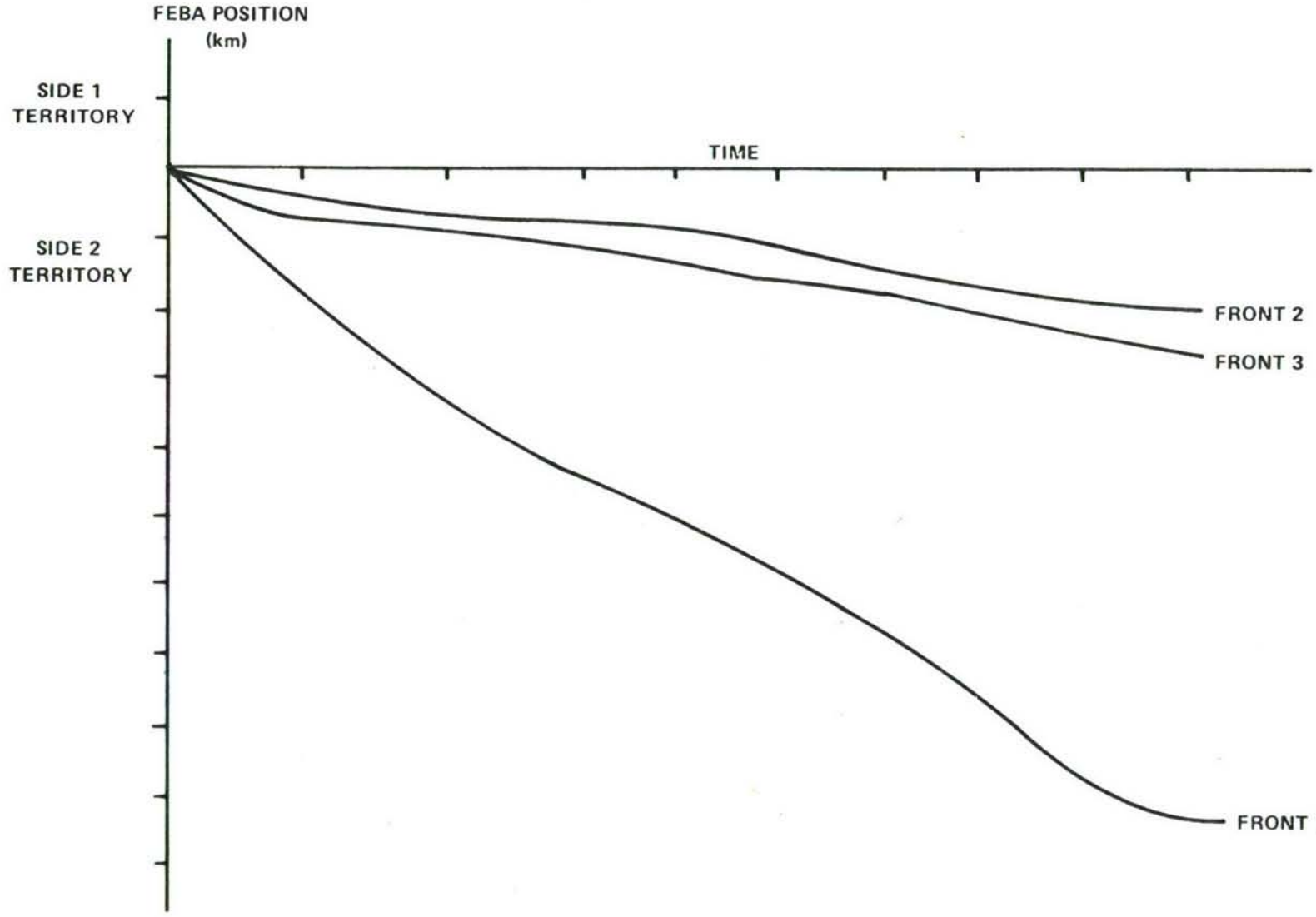
SECTION III
CONVENTIONAL COMBAT

This section shows example outcomes of a conventional conflict modeled by COMBAT II. A fully-mobilized Side 1 force attacks an inferior force on Side 2. The forces are arrayed in three fronts with both sides giving priority to the attack or defense of Front 1. Side 1 is constrained by supplies and logistic capabilities whereas Side 2 is constrained by inadequate reserve forces. The conflict terminates when Side 1 exhausts its supplies.

CONVENTIONAL CONFLICT FEBA POSITIONS VS. TIME

An aggregate measure of the outcome of theater conflict is the trace of the FEBA position. COMBAT II provides such an index for each of three fronts. Shown here is the outcome of the conventional conflict outlined earlier. It details the ground gained by Side 1 and shows the effect of the resource coupling equations when Side 1 is commanded to give priority to Front 1 movement. Side 1's movement objectives for the 3 Fronts were weighted 10:2:3. Side 2 defended in the priority ratio of 5:4:4 for Fronts 1, 2 and 3 respectively.

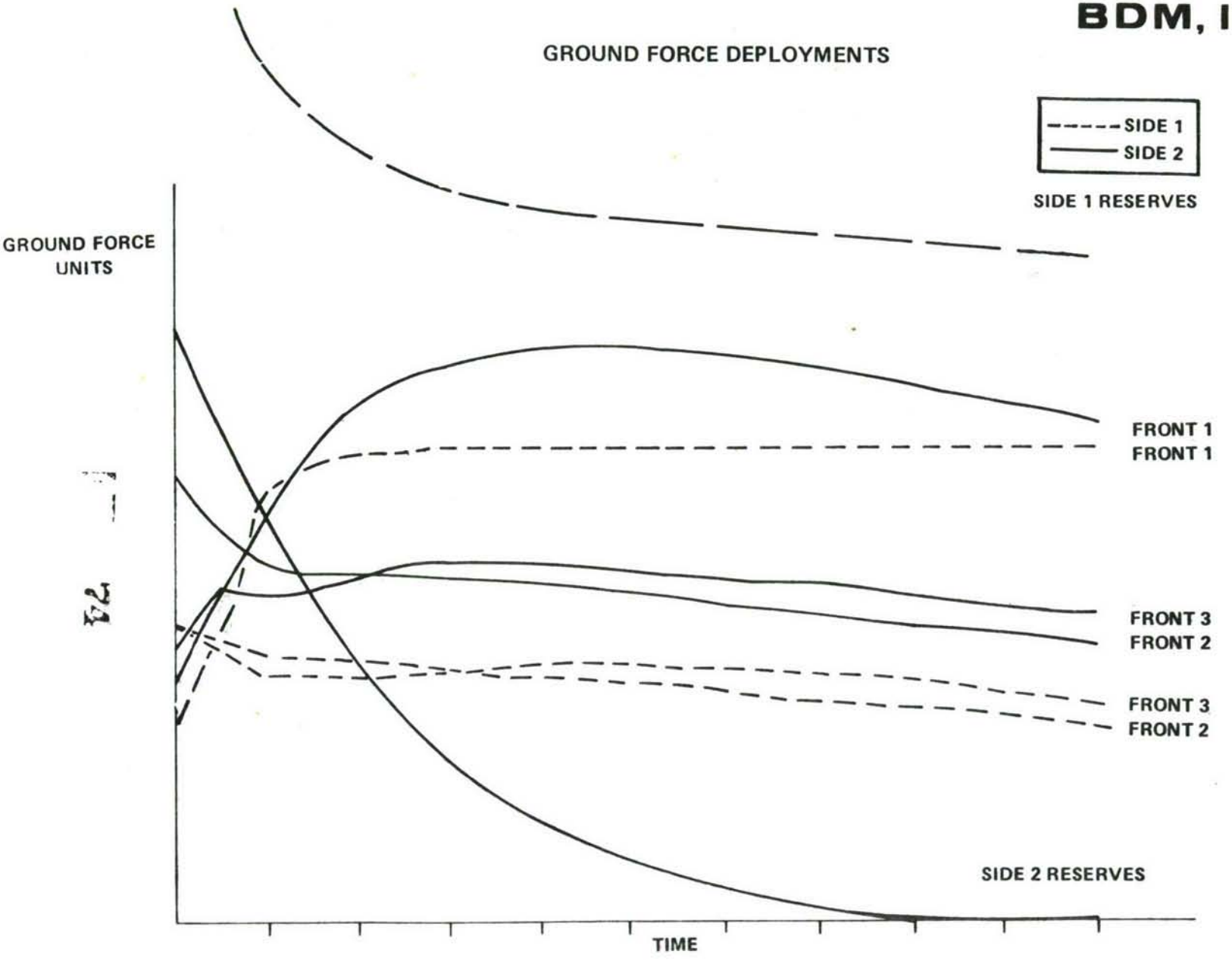
CONVENTIONAL CONFLICT FEBA POSITIONS VS. TIME



RATE OF FEBA MOVEMENT FRONT 1

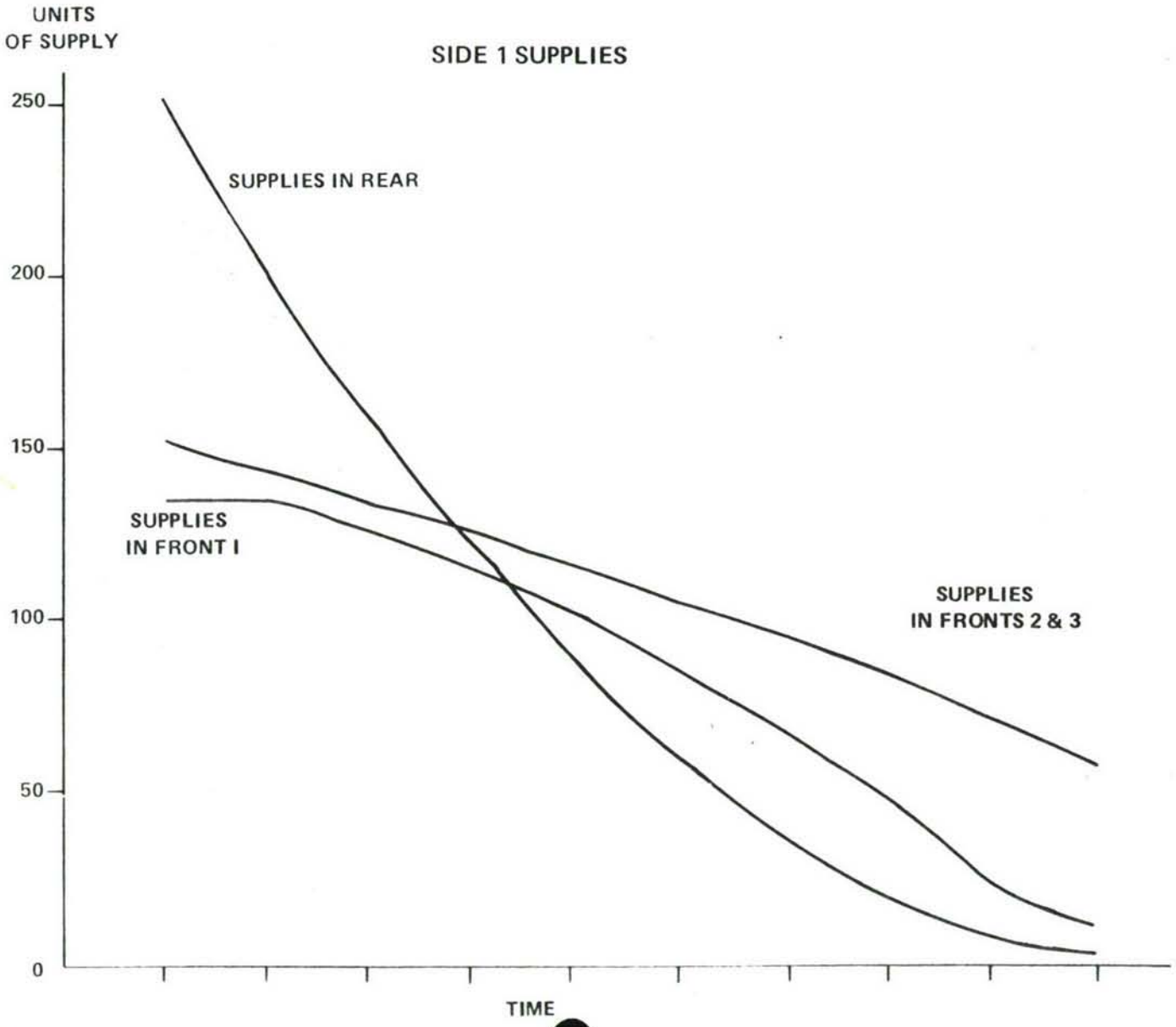
A more detailed examination of the rate of movement of Front 1 gives a better picture of the effect of resource constraints. Side 2 slows the rate of advance by deploying reserves to Front 1; these reserves, however, are eventually exhausted. Side 1 is unable to mass sufficient forces to overwhelm Side 2 before it runs out of supplies; the attack then grinds to a halt.

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GROUND FORCE DEPLOYMENTS
SIDE 1
SIDE 2
SIDE 1 RESERVES
GROUND FORCE UNITS
FRONT 1
FRONT 1
FRONT 3
FRONT 2
FRONT 3
FRONT 2
SIDE 2 RESERVES
TIME

SIDE 1 SUPPLIES

The supply constraints on Side 1 are shown in detail here. Along with the dramatic draw-down of reserve supplies it shows that although a larger force operates in Front 1, higher consumption and attrition rates coupled with logistics constraints cause forces in Front 1 to operate at a lower supply/force ratio than forces in other Fronts. Eventually, reserve supplies are exhausted and combat in Front 1 can no longer be sustained.


UNITS
OF SUPPLY
SIDE 1 SUPPLIES
250
200
150
100
50
0
SUPPLIES IN REAR
SUPPLIES
IN FRONT I
SUPPLIES
IN FRONTS 2 & 3
TIME

SECTION IV

MIXED CONVENTIONAL/TACTICAL NUCLEAR COMBAT

Having examined how COMBAT II plays a conventional war, this Section shows how nuclear systems affect theater conflict. In particular, it illustrates how variables such as weapon inventories, acquisition factors, weapon allocations, and expenditure rates interact to affect the outcome of theater tactical nuclear war.

The base case mixed conflict plays smaller, roughly equal forces. Side 1 preempts with its full array of tactical nuclear weapons and theater-allocated air forces. Side 2 responds in kind one hour after the attack. The advantage alternates between Side 1 and Side 2 while nuclear inventories last, but shifts to the larger surviving conventional force after nuclear systems are exhausted.

This base case nuclear conflict highlights important sensitivities, some of which are to be examined in the next section.

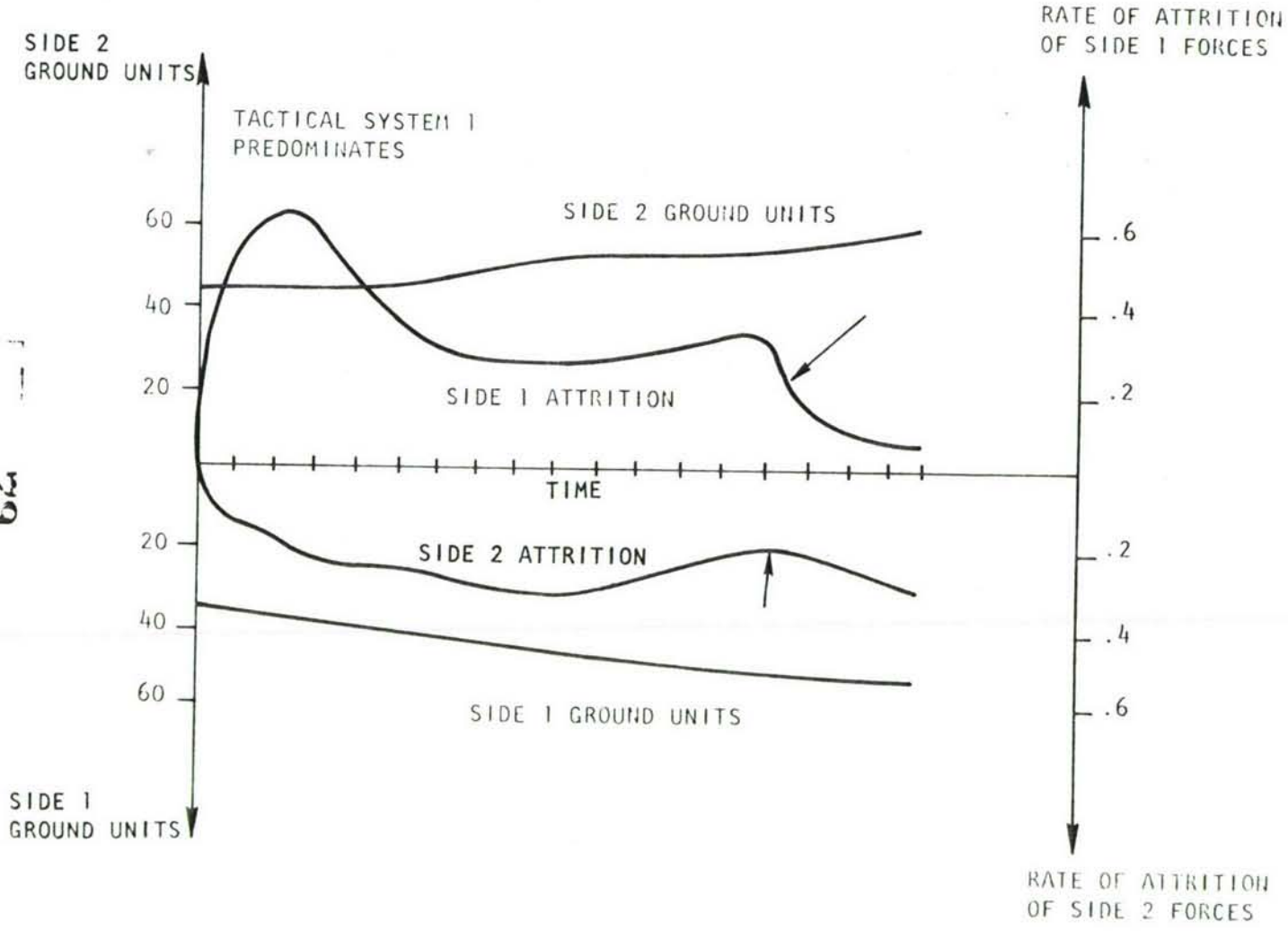
NUCLEAR CONFLICT FEBA POSITION ON FRONT 1 VS. TIME

FEBA Movement on Front 1 during the early stages of conflict shows the effect of the Side 1 preemptive attack and a massive response. First, Side 2 forces are pushed back while they are still in a conventional posture. After 1 hour, Side 2 responds with its nuclear systems, recovers lost territory and drives into Side 1 territory until key systems are exhausted.

The alternation of movement is due primarily to the dominant effects of the application and exhaustion of nuclear systems. Ground force numbers are relatively stable. These variabilities are taken up next in a decomposition of combat capability.

DECOMPOSITION OF COMBAT CAPABILITY IN FRONT I

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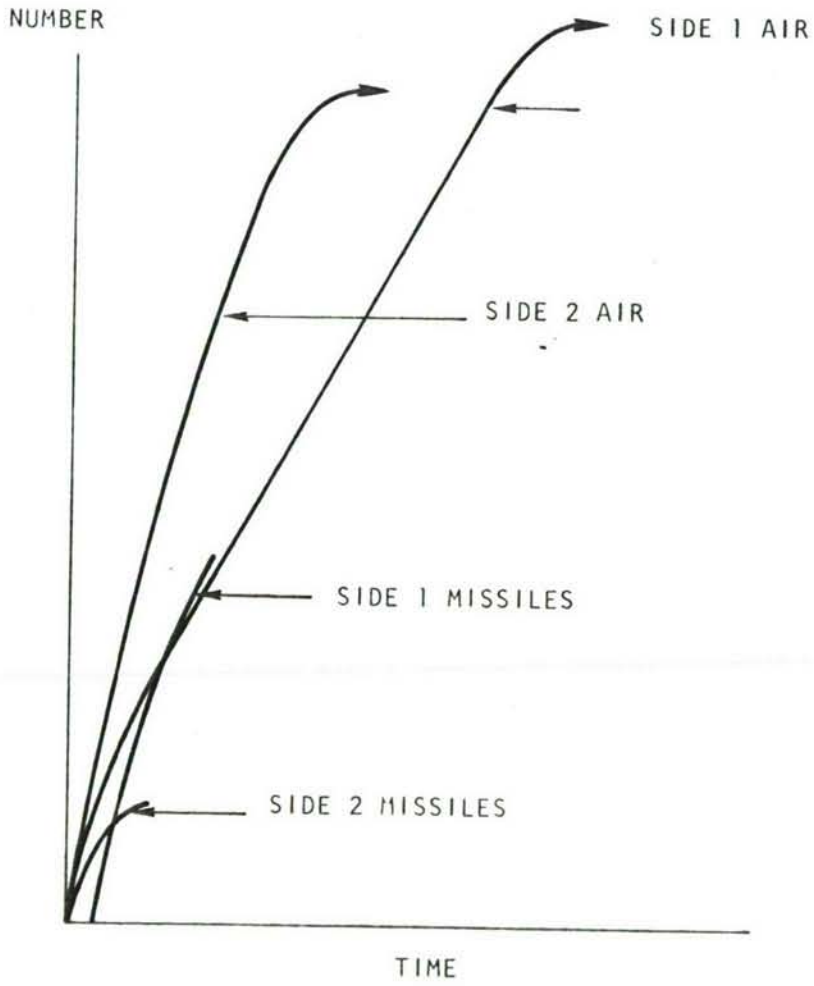
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SUMMARY OF CENTRAL EXCHANGES

A summary displays the following about the exchange of centrally- or theater-allocated missiles:

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SUMMARY OF CENTRAL EXCHANGES



TEMPORAL MAP OF DRIVING EVENTS

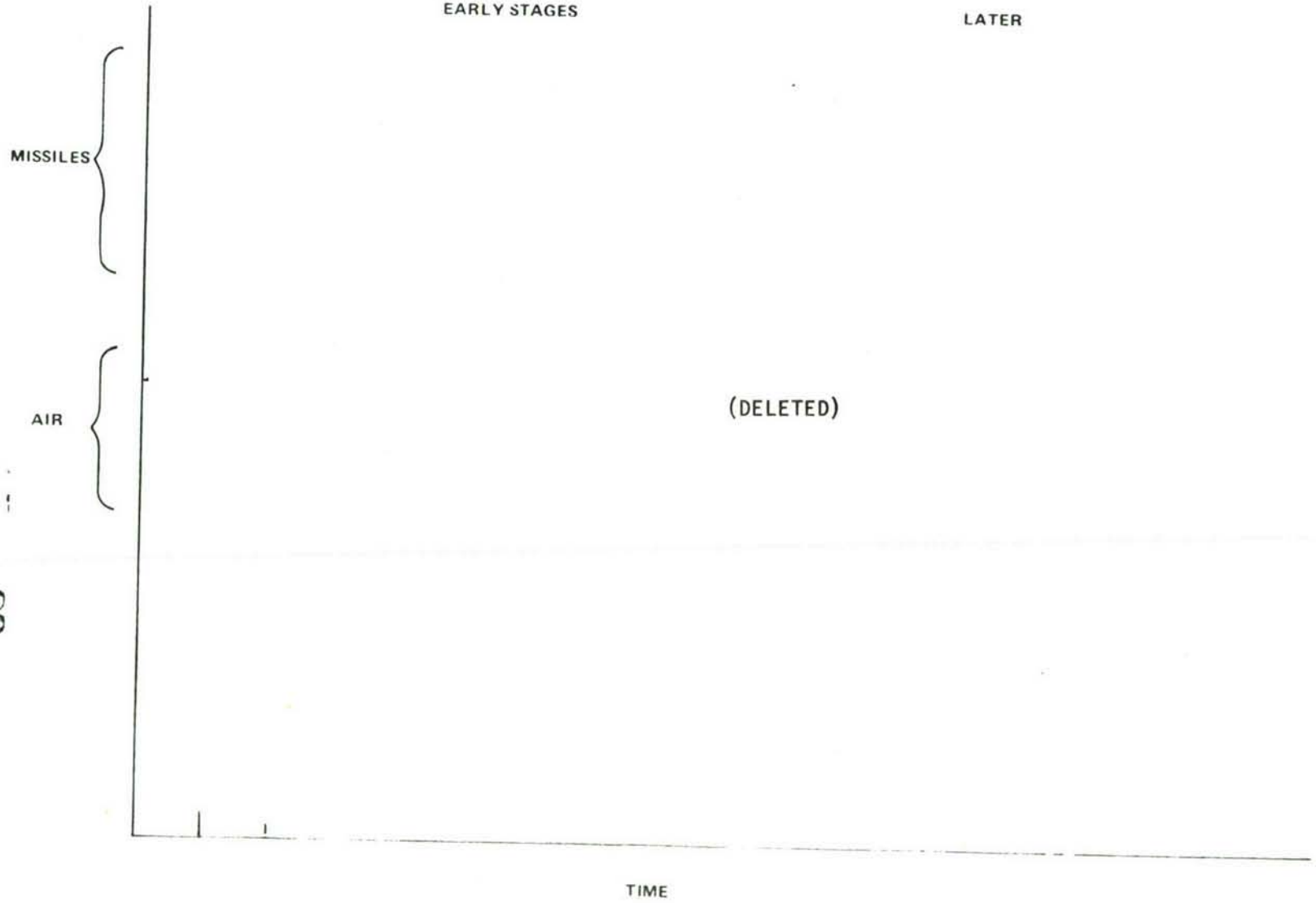
The Temporal Map depicts those events which appear to have driven the base case mixed conflict as modeled in COMBAT II. Key turning points are in boxes. The figure highlights two types of events which deserve detailed investigation in follow-on studies:

a. Those events which are determined by input logic, i.e., air and missile allocations. Insofar as possible, the logic incorporated in COMBAT II accurately reflects both contemporary doctrine and realistic combat interactions. Where input logic results in less-than-optimum actions on either side, a review of the situation may highlight deficiencies or advantages at the doctrinal or theoretical level.

b. Those events which are determined by real-world conditions or resource constraints, i.e., warhead/missile inventories. Further investigation of these areas may reflect effective and inexpensive policy options for the decision-maker. COMBAT II facilitates insights into the implications of policy alternatives in terms of their ultimate effects on theater conflict.

The COMBAT II model also heightens the visibility of critical data and of modeling approaches. For example, high kill rates in the rear area are determined primarily by acquisition factors. Sensitivity to acquisition rates should be a subject of follow-on studies.

TEMPORAL MAP OF DRIVING EVENTS



KEY INPUTS

Exercise of the COMBAT II model and analysis of pilot cases has highlighted several areas where input data are key to model outcomes. These impact on a fundamental understanding of theater warfare. Four such areas are identified thus far:

1) Allocation factors.--How are systems allocated in a near-optimum fashion to affect the overall outcome of theater conflict? It has become obvious that allocations which reflect our understanding of current U.S. and Soviet doctrines of theater conflict are less than optimum.

2) Acquisition factors.--Analyses of initial trial runs reveal the degree to which acquisition drives the firing rate and effectiveness of tactical nuclear systems and, thus, the Frontal war. Efforts to improve data and sub-models in this area have been frustrated by numerous conflicting assumptions.

3) Kill factors.--Generalizations about aggregate kill probabilities for small nuclear weapons against tactical formations are based on less-than-reliable data.

4) Maximum expenditure rates.--Initial trials cast doubt on the viability of nuclear operations at maximum expenditure rates. There appears to be no systematic logic with which to optimize theater-wide fire discipline.

These key input areas are likely candidates for sensitivity analyses and for further model development. Some areas where preliminary sensitivity analyses have already been conducted are discussed next.

KEY INPUTS

- ALLOCATION FACTORS
- ACQUISITION FACTORS
- KILL FACTORS
- MAXIMUM EXPENDITURE RATES

SECTION V
EXAMPLE SENSITIVITIES

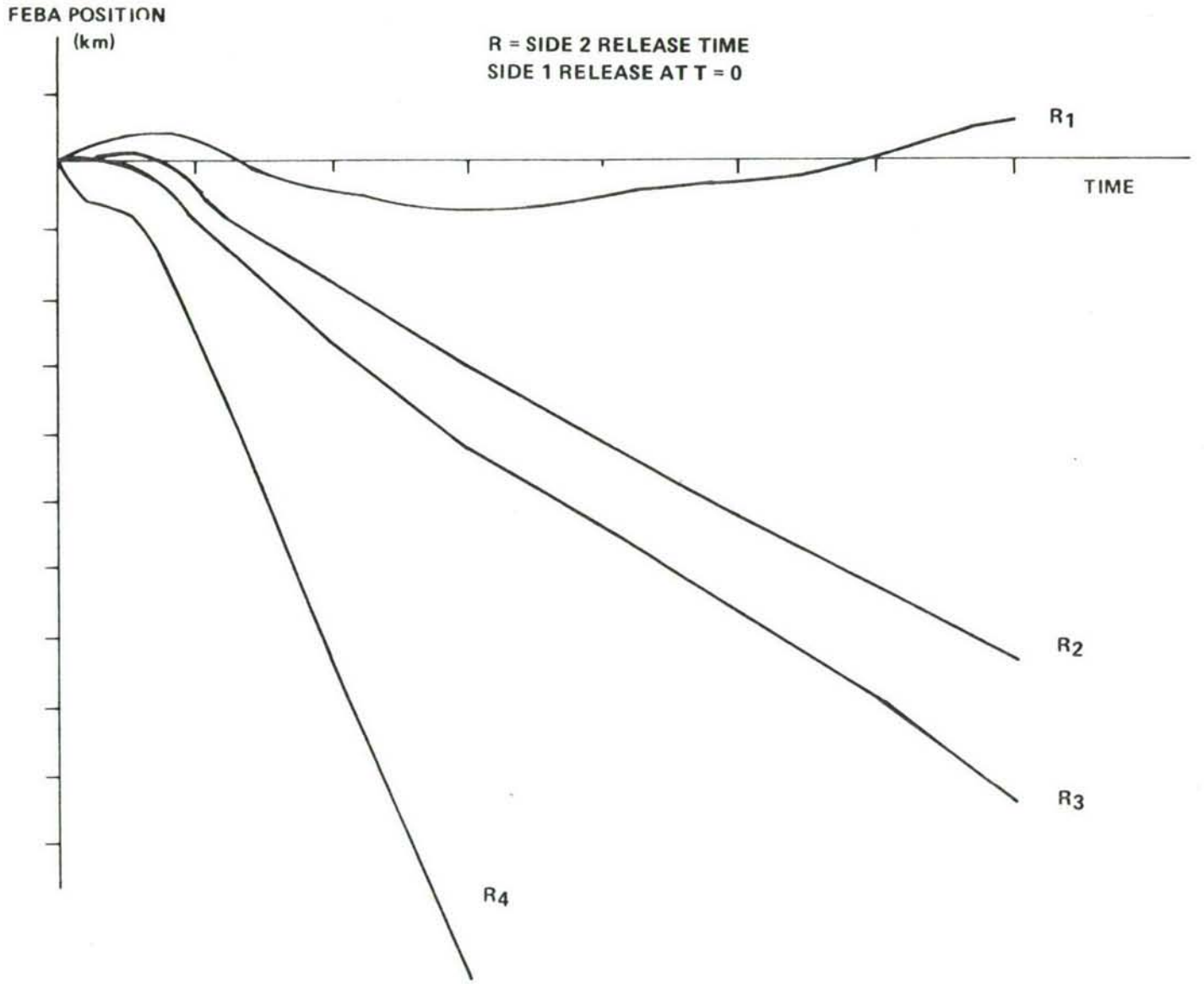
Having highlighted some of the sensitivities which were revealed during the course of the pilot study, this section now turns to examples of sensitivities examined early in model development. These were of the nature of benchmark trials to demonstrate COMBAT II operations. Nevertheless, these excursions from the base case illuminate the advantages of testing force options and critical assumptions in a theater context.

VARIATION OF RELEASE TIME

The variation of release time illustrates the advantages of preemptive use of nuclear weapons. Such a display quantifies how the timeliness of a release decision affects the overall outcome of conflict and yields an order-of-magnitude estimate of the response required if an otherwise capable force is to defend itself successfully.

It should be noted that the sensitivity to release time is also dependent on initial conditions of alert status, mobilization, force dispersal, and warning which can also be varied in COMBAT II.

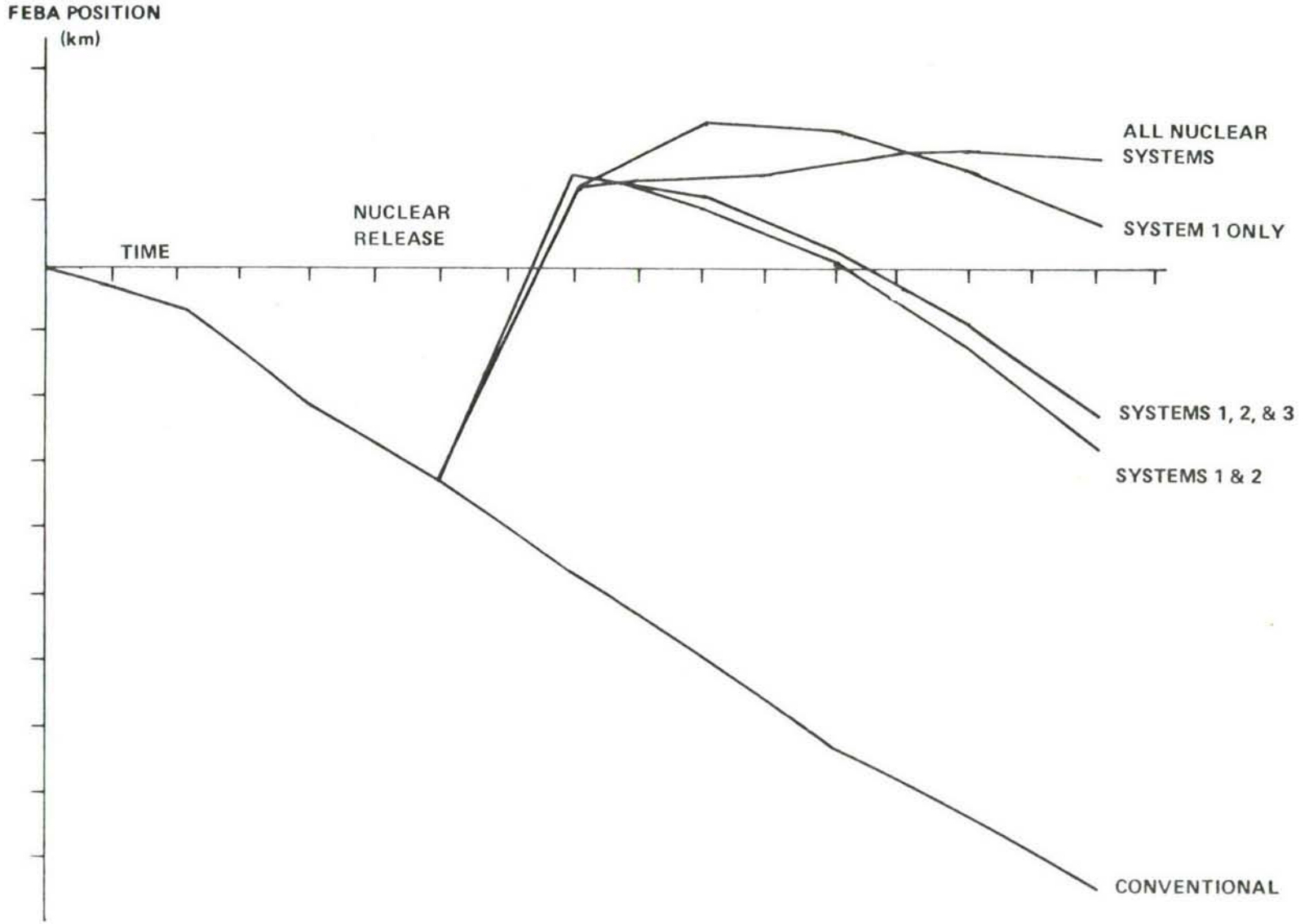
VARIATION OF RELEASE TIME



VARIATION OF FORCE APPLICATION

The variation of force application affords insights into the doctrine of selected release. In these excursions the two sides released different sets of like systems after a certain point in the conventional conflict. The display shows in which areas of weaponry a side has the advantage and the marginal utility of the various weapons in the overall arsenal. The variation of force application is also a theater view of force-posture alternatives.

VARIATION OF FORCE APPLICATION



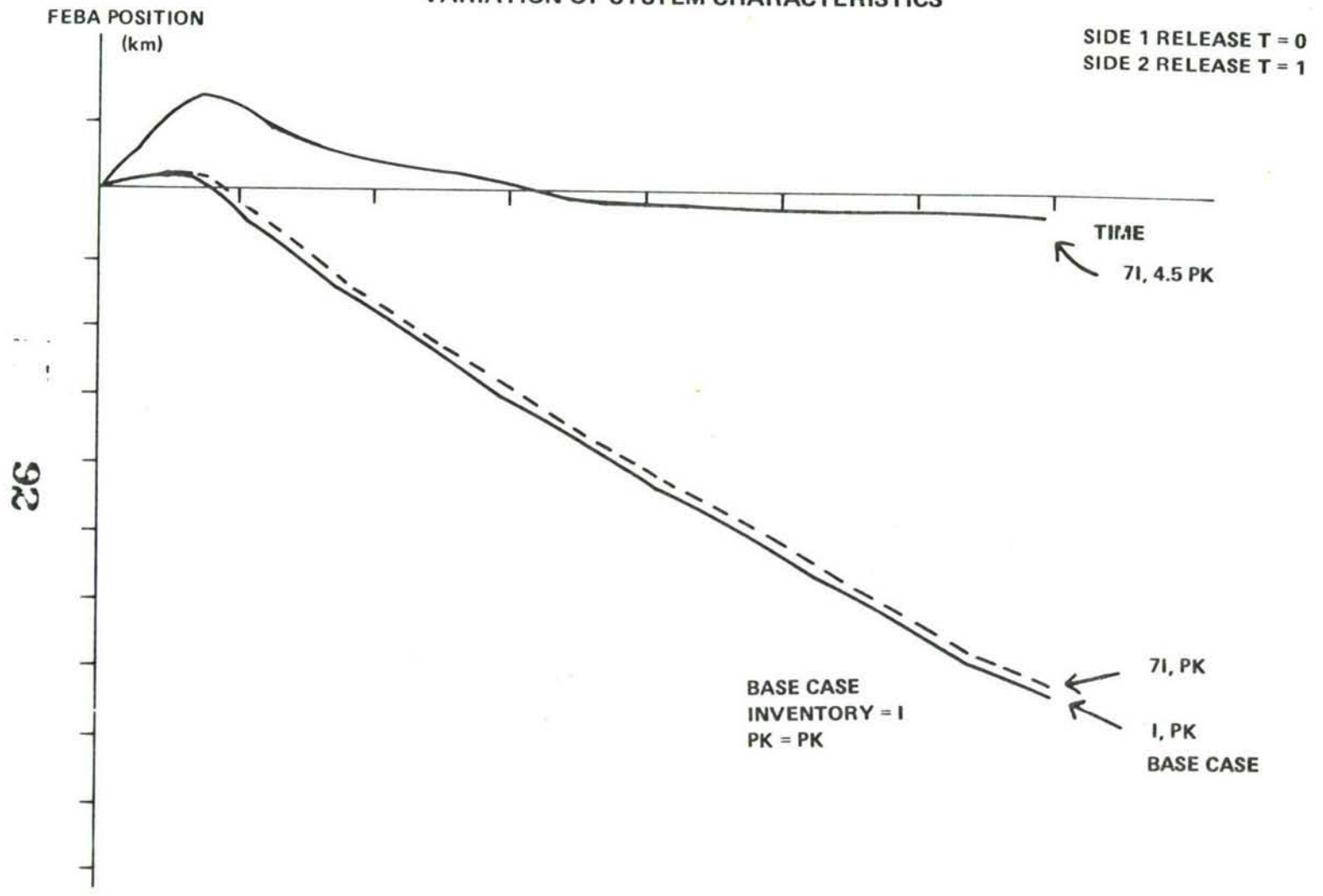
VARIATION OF SYSTEM CHARACTERISTICS

COMBAT II lends increased sophistication to arguments about quantity versus quality. Shown here is the operation of a current tactical system compared with hypothetical future deployments. A seven-fold increase in the number of systems deployed has relatively little impact on the conflict given prevailing operational constraints. Coupled with an improved single-shot probability of kill, however, the increased numbers have a dramatic impact on redressing a theater balance.

The variation of system and force parameters in a theater model can be a powerful tool to prevent sub-optimization in the design and acquisition cycle for new systems.

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VARIATION OF SYSTEM CHARACTERISTICS



SECTION VI
SUMMARY AND CURRENT STATUS

This last section summarizes the major features of the COMBAT II methodology and outlines model development, data refinement, and model application activities currently being conducted under direction of the Defense Nuclear Agency.

SUMMARY

This summary recaps the original objectives which guided development of COMBAT II. These objectives are the criteria for assessment of the methodology and remain the objectives of follow-on development.

SUMMARY

A POWERFUL TOOL FOR AGGREGATE THEATER ANALYSES

FLEXIBLE ARCHITECTURE FOR INCREASED RESOLUTION

TRANSPARENT CALCULATIONS

ANALYST ORIENTATION

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APPLICATIONS

Production activity for the Defense Nuclear Agency will focus on the areas indicated.

APPLICATIONS

SENSITIVITY ANALYSES

- TIMING
- FORCE COMPOSITION
- WEAPON CHARACTERISTICS
- WARNING AND FORCE READINESS

ISSUE ANALYSES FOR:

- DEFENSE NUCLEAR AGENCY
- DOD AD HOC PANEL ON NUCLEAR POLICY

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CONTINUING DEVELOPMENT

The Defense Nuclear Agency has contracted for further development of the COMBAT II Methodology in the areas indicated.

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CONTINUING DEVELOPMENT

SUB-MODEL IMPROVEMENT

- TARGET ACQUISITION
- SUPPLY FLOWS AND ATTRITION

BASE DATA REFINEMENT

- FOCUSED ON SENSITIVE VARIABLES
- MORE DETAILED MICRO-MODEL INPUTS
- RESPONSIVE TO CRITIQUES BY ANALYTICAL COMMUNITY

CODE ADVANCES

- OPTIMAL ALLOCATION-DECISION RULES
- ANALOG (CALCOMP) DISPLAYS
- ANALYST-ORIENTED DOCUMENTATION

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THE BDM CORPORATION

1920 Aline Avenue
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Phone (703) 893-0750

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INDICES OF EFFECTIVENESS IN GENERAL PURPOSE FORCE ANALYSIS

JOHN R. BODE

FOREWORD

This is a reprint of a paper written while the author was a student at the Industrial College of the Armed Forces. It was intended primarily to provide a perspective for individuals with little or no background in military modeling. Experience has shown, however, that there are some ideas of interest to experienced analysts. Most of these appear in Chapter II. The main points are summarized below.

The discussion of dynamic modeling in Chapter II shows how detail is successively aggregated from a series of one-on-one exchanges up through estimates of theater level force comparisons. A key observation is that at some point in modeling detailed description of the interactions between physical things ceases and estimation of relationships based on derived capability measures begins. For example, take the relationship between FEBA movement and the quantities, qualities and fire power of opposing forces. This is a root problem of military force effectiveness modeling. There are no known, explicit, physical laws upon which to base these relationships; nor can they (for one reason or another) be empirically based. Yet modeling of total force effectiveness requires that these kinds of relationships be described.

Because empirical verification has proved intractable, many of the fundamental concepts of aggregate models are largely heuristic. This can confound the physicist or engineer who is trained to work with reproducible data and explicit physical laws. The paper proposes that we make the most of this unpleasant circumstance by insisting that all models be transparent to the analyst and decision maker. This would allow each and every calculation to be tracked to the extent that the impact of all heuristics and known relationships could be evaluated.

Since this paper was written, Dr. Dunn, Mr. Swinson, the author, and others at BDM have developed a differential equation model that meets the transparency properties noted above. This new model, COMBAT II, also deals forthrightly with the problem of heuristics. Papers discussing the theory of the COMBAT II model are available upon request to the author at BDM.



John R. Bode
Director, Tactical Systems
703-893-0750

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CHAPTER I
INTRODUCTION

A. BACKGROUND

Substantial efforts are underway in the United States and other nations to develop improved analytical techniques for assessing the relative capabilities of opposing general purpose combat forces. Decision variables include numbers of weapons systems, quality of weapons, mixes of weapons, deployments, and strategies of employment. Applications are force structure planning, weapons systems research, development, and procurement, mutual and balanced force reductions (MBFR), and others.

Some progress has been made with detailed analyses and "war game" models requiring many man hours of effort and considerable expense to exercise. These methods have proved useful in many instances, although much remains to be done to improve scope and generality. The dynamic "war game" models treat time-dependent interactions of the forces. In general the models cannot keep track over time of every man, weapon, munition, and unit involved in complex military actions. Consequently, some composite capabilities of weapons, units or components must be estimated.

Estimates of aggregate capabilities, expressed in suitable form, are both inputs to, and outputs of, dynamic models. For clarity such aggregates will be referred to in this paper as Military Effectiveness Indices (MEI). Much effort has been expended to develop adequate MEI for use in detailed dynamic models.

In addition there are also efforts to develop MEI that are suitable for direct calculation of relative military effectiveness without recourse to more complex "war gaming." These are usually referred to as static or potential MEI because they represent "ex-ante" assessments. In other words, they assess starting conditions only, and relate to what could happen, not what does happen in the real world or a model.

With due consideration given to the approximate nature of any static MEI, strong incentives remain for developing static indices that are sufficiently general to serve as rules of thumb for comparing forces and bounding the results of complex models. There is a considerable divergence of opinion as to whether or not such rule of thumb indices are feasible, but they would be very useful supplements to the intuition of the decision maker and analyst when structuring problems, identifying alternatives for detailed considerations, and checking obscure analyses.

This paper examines MEI in the dynamic and static contexts discussed above. The role MEI play in dynamic models is explored. Attempts to develop static MEI for direct force comparisons are described. Feasibility of rule-of-thumb static MEI is discussed, and suggestions are made for future work.

B. SEMANTICS

It is desirable to distinguish between four commonly used terms which may have widely varying connotations. These are model, index, methodology, and analysis. The following meanings are used in this paper. A model is a mathematical representation of a process which may or may not be physical. An index is a single number that is either computed from an explicit mathematical relationship between specific factors, or is derived from the results of a model or combination of models, or by judgment. A MEI is defined in this paper as a single number that represents some relevant capability. One MEI does not necessarily describe the total capability of a force; a series of MEI may be needed to do this. Examples of MEI are given in the following section.

A methodology is a specified logical sequence by which results are obtained. The term is used to describe the way indices are calculated, and the way that specific calculations are made within models. Furthermore, sub-models are often combined by methodologies to make larger models, and finally models are combined and organized by methodologies to make

analyses. The analysis is the complete product from awareness of a problem to presenting completed evaluation of alternatives to the decision maker.

Indices, models, and methodologies are all likely to have names, and it is not uncommon to find a named index used in a named model in a named methodology, which can confuse the unwary, to say the least.

C. EXAMPLES OF MEI

This short section previews the subject by listing a few examples of MEI. As stated previously, MEI are single numbers that express some relevant military capability. Simple number of weapons of a certain type in a force is one kind of MEI.

Common MEI for comparing aircraft are: sorties flown per day, targets killed per sortie, and aircraft lost per sortie. Another for ground weapons could be rounds fired per day, and one appropriate for ground and air is enemy killed per friendly lost, which is commonly referred to as the exchange ratio.

The probability of killing a specific type of target with a specific munition, usually calculated by a standard method, is a common MEI, the P_k. There is usually some area around the point of impact for which a specific munition could inflict a certain P_k. For a specified P_k, this is known as the lethal area of the munition. By combining lethal area and rounds per day, one can obtain an important index called the Fire Power Potential (FPP), described in more detail later.

Outcomes of battles or operations might be expressed in casualties, or rates of advance or weight of ordnance delivered in support of ground forces.

Almost any MEI can be defined provided it can be stated as a single number and used to represent a unit or an aggregate capability. A number of specific MEI of interest are described in some detail in later sections, first in the context of use in dynamic models, and then as static or potential indicators.

CHAPTER II
DYNAMIC USE OF MEI

A. CONCEPT OF THE HIERARCHY OF MODELS

This section develops the concept of a hierarchy of analytical models based on the level of interaction treated and shows the role played by MEI. Figure 1 below displays the hierarchical concept. The term dialectical is used in the manner of Georgescu-Roegen (1) to mean that it is not possible to define precise boundaries between the levels. As will be seen later, there are some analytical models that can be categorized in more than one level, but in the main the levels serve as a good point of departure for discussing a plethora of models and methodologies.

At a given level, the analytical procedure usually follows the sequence of establishing a scenario, modeling the physical processes, assessing the outcomes over time for various proportions of the trade-off variables, and selecting the trade-off quantities. For instance, one might compare an antitank missile to other ground based antitank weapons at the encounter level, and select the mix that resulted in the greatest number of enemy tanks destroyed according to the model chosen and within specified constraints of the total cost and total friendly casualties. However, for MBFR, the interest is in the ability to achieve specific military goals at the theater level with various options of total force size and composition.

The levels in Figure 1 are ordered vertically. The arrows signify that information passes between the levels. Usually the upper level sets the stage (scenario) for the lower level, and the lower passes an outcome into the upper to be used in a more general treatment. Even when the lower level produces the results used in the final analysis, assessments at the higher level are required in order to establish the scenario at the level of primary interest.

LEVEL	ASSESSMENTS	TRADE-OFFS
Global	Balance of Power	National Objectives
↕ Nations, Geopolitics	Economics	
Theater	Specific Military Objectives	Total Force Size, Composition, Deployment, Employment
↕ Forces, Climatology, Geography		
Battle	Casualties	Numbers and Types of Units
↕ Units, Weather, Topography	Movement Rates	Unit Tactics
	Weapons Attrition	
Encounter	Targets Killed per Day/Sortie	Weapons Mixes
↕ Multiple Weapons Types, Ceiling/Visibility, Terrain	Exchange Ratios	Sub-unit Tactics
Engagement	Probability of Killing a Single Target	Weapons Tactics and Design Features
↕ Single Weapons Types, Controlled Conditions	Probability of Loss to Single Attritor Type	
Operations	Endurance	Design Specifications
↕ Weapon Properties	Range/Speed	
	Fire Rate	
Engineering	Weight	Design Features
Weapon Configuration	Power	
	Size	

Figure 1 Dialectical Hierarchy of Interactions (Showing Typical Characteristics of Levels)

The dotted line above the lower three levels divides the hierarchy into two regions. Above the line two-sided combat must be considered. This implies that any model in this region must include the enemy. Presumably the enemy should be allowed freedom of action at least comparable to the friendly choices available at the level of interaction chosen for the analysis, i.e., within the scenario specified. This gives rise to a common concern with specific scenarios, because there is usually a wide latitude of possibilities open to each adversary, both inside and outside the boundaries of the scenario. Conceptually, this would be resolved by considering all possibilities in the specific scenario, and then developing other possible scenarios with a model at the next higher level of interaction. Later discussion will show that the capability to do this is extremely limited.

Below the dotted line in Figure 1 it is not necessary to consider the enemy explicitly. One can evaluate operational and engineering factors in great depth without considering the adversary. This is one reason why models and methodologies are very highly developed for these levels. For example, it is possible to make quite accurate predictions of range/payload/loiter performance of aircraft. It is only the attempt to assess the impact of range/payload/loiter on combat objectives (i.e., move into the upper levels) that is difficult.

The following paragraphs give examples of models used or proposed at each of the hierarchical levels. The purpose of this is to show how models at various levels fit together, and that military effectiveness indices (MEI) of some type are necessary in all the models above the encounter level. The examples are not exhaustive by any means, but the sample is sufficiently large to give the reader a feel for the area. The number of models discussed limits the treatment of each, but references are provided for those interested in greater detail.

B. GLOBAL LEVEL MODELS

At this level the trade-offs are made among national objectives and assessments must be made in terms of national economic, political, and social factors.

Some interesting conceptual approaches at this level are based on two-person game theory. A two-person game occurs if each of two opponents has a number of options available to exercise, and if there is some outcome which is determined by the joint options selected by each opponent. If the outcome can be expressed as a single number, it is a MEI. Figure 2 below illustrates a game where one player's gain (MEI) is exactly the other player's loss. This is called a zero-sum game. The choice made by each player is called the strategy. The possible outcome MEI are called payoffs. If A and B each choose strategy 2, the payoff to A is 20, and to B is -20. Assuming that each side knows the payoff to both, and that each side must choose simultaneously, how should the players make choices? If A chooses 2 in order to get 20 points, B could choose 1 so that A would get nothing. A formal approach called the minimax criterion, states that A should choose 1 and B should choose 1. In this way A can guarantee a payoff of at least 10 and B can guarantee a loss no greater than 10. The value of the game is said to be 10.

Figure 3 shows a simple non-zero sum game. In this game both players gain for every strategy. By using the minimax criteria, each side chooses so as to guarantee a payoff of 2 to each. Note however, that if they could agree to play strategy 2, each would be better off. These are characteristics of non-zero sum games. While there may be payoffs where each side loses, payoffs where one gains and one loses, or payoffs where both win, it is generally true that there is at least one strategy that will guarantee a minimum payoff (or loss) to each side. But there is also in general at least one strategy which would provide a better payoff to each player if they bargain to employ it.

Global applications of this theory are conceptualized through specification of the strategy alternatives in terms of military force size, composition, and world-wide deployment, and of political-economic instruments of power such as treaties and trade agreements. The payoffs

		Player B	
		Strategy 1	Strategy 2
Player A	Strategy 1	10,-10*	15,-15
	Strategy 2	0,0	20,-20

Figure 2. A Simple Zero - Sum Game

		Player B	
		Strategy 1	Strategy 2
Player A	Strategy 1	2,2	4,1
	Strategy 2	1,4	5,3

Figure 3. A Simple Non-Zero - Sum Game

*Payoff to A, Payoff to B, if A plays strategy 1 and B plays strategy 1.

(MEI) must be specified in terms of global national objectives. This theory makes explicit the fact that national objectives are not only achieved through military, political and economic instruments of power, but are also enhanced by international bargaining.

A theory of bargaining in non-zero sum games was proposed by Nash (2) and applied to military theory by Pugh and Mayberry (3), and Brown, Johnson, and Dresher(4). According to Pugh and Mayberry the theory shows that military forces have an "important role in peace-time bargaining and negotiation as well as their role in actual combat." This occurs because the Nash bargaining theory clearly shows that the result of the bargained solution depends on the relative strength of the players. In a nutshell, one must negotiate from a position of strength, which is one theoretical statement that agrees with common sense.

In addition, the concept of the theory as developed by Pugh and Mayberry is that for any postulated global bargaining value there is a means, in principle, of determining an optimal strategy for the military, political, and economic options of each opponent. This would provide a conceptual basis for totally optimizing military forces.

Unfortunately, while the theory is established in principle, it has little practical application at the global level. It has not been possible to quantify all the relevant values of the nation to obtain payoff MEI that are useful in the game solution techniques. According to Pugh and Mayberry:

> "The basic payoffs should include not only the tangible cost of battle in lives and material, but also intangible factors such as prestige, honor, and the tangible or intangible values of issues in dispute. This is a large order. Obviously, no such all-inclusive value or utility function is likely to be used in any practical evaluation of general-purpose military forces."

Furthermore, these value-assessment MEI must be quantified for the opponent, which is even more difficult than assessing and quantifying our own goals.

Pugh and Mayberry give simplifying assumptions that reduce the difficulty of the problem somewhat. In a follow-on paper, Pugh (5) gives a general approach to working out strategies. However, even under simplifying assumptions relative to values of payoffs, the extremely large number of variables needed to describe general purpose combat has inhibited applications at the global level.[1]

To sum up global level models, seeds of theory and concept exist. The conceptual framework is based on two propositions: that national strategies can be defined for combined military, political, and economic activities, and that for each strategy a payoff MEI can be computed. There are two categories of practical difficulties in obtaining solutions. First, known mathematical techniques can accommodate only a very small number of specific strategies compared to the enormous number of possible variations. Much work remains to expand this capability. Second, while the payoff MEI are postulated at the global level, no useful means of calculating such indices have been found.

Thus the role of MEI at the global level is more conceptual than practical. The models are based on postulated existence of MEI that represent payoffs in terms of national values and objectives. It remains a challenge to invent such MEI.

C. THEATER LEVEL AND BATTLE LEVEL MODELS

Theater level assessments have received a great deal of attention in recent years, owing in part to adjustments within NATO and interest in the balance between the military capabilities of the NATO and the Warsaw Pact nations. The trade-off variables of interest are total force size, composition of the forces, and deployment and employment of the forces.

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[1] A methodology was developed by Brown, Johnson, and Dresher (4) also following Nash non-zero-sum game theory. This approach is beyond the scope of this paper as it includes escalation to limited nuclear or nuclear conflict. However, the paper is recommended to anyone interested in the theory of military bargaining. Also a zero-sum approach along the lines suggested by Pugh was developed in the TAC CONTENDER model.

Composition includes the mix of land, sea, and air forces, and the components of these forces such as units of armor, infantry, air superiority fighters, ground attack aircraft, etc. Analyses are conducted to evaluate the capability of each opponent to achieve selected objectives under varying assumptions relative to the trade-off variables.

Figure 4 below shows some of the elements which a model or methodology designed for analysis at theater level should consider. First an objective must be set. As stated in Section B, in a theoretically optimized methodology the objectives would be set by the global model, but this is not feasible with present techniques. Therefore, objectives are usually established by judgment.

The models used for analysis should account for the impact that the ground forces have on each other in the battle situation. This should include variations due to differences in composition of the ground units. The models should also account for the impact of the air forces on the ground battles and upon the opponents' air forces and logistics. Naval contributions to logistics and air power should be included if appropriate. Geographical factors and climatology should be considered also for their influence upon operations and tactics. Command and control facilities and capabilities are also very significant.

Because the forces could be in a number of deployments when hostilities begin, and because of command and control, and mobility of both ground and air units, it is especially desirable that models be able to account for strategy variations during the sequence of theater level combat. Strategy variations include choices between the time and locations of battles, and the numbers and types of units involved in the battles. For example, note that in Figure 4 the ground force A-1 is engaged in battles with both B-1 and B-2. One would expect the outcome to be affected if B-2 is shifted against A-2 instead. Furthermore, there are continual allocation decisions to be made for the air forces. Should they do close air support, airfield attack, interdiction, air defense, or battlefield defense?

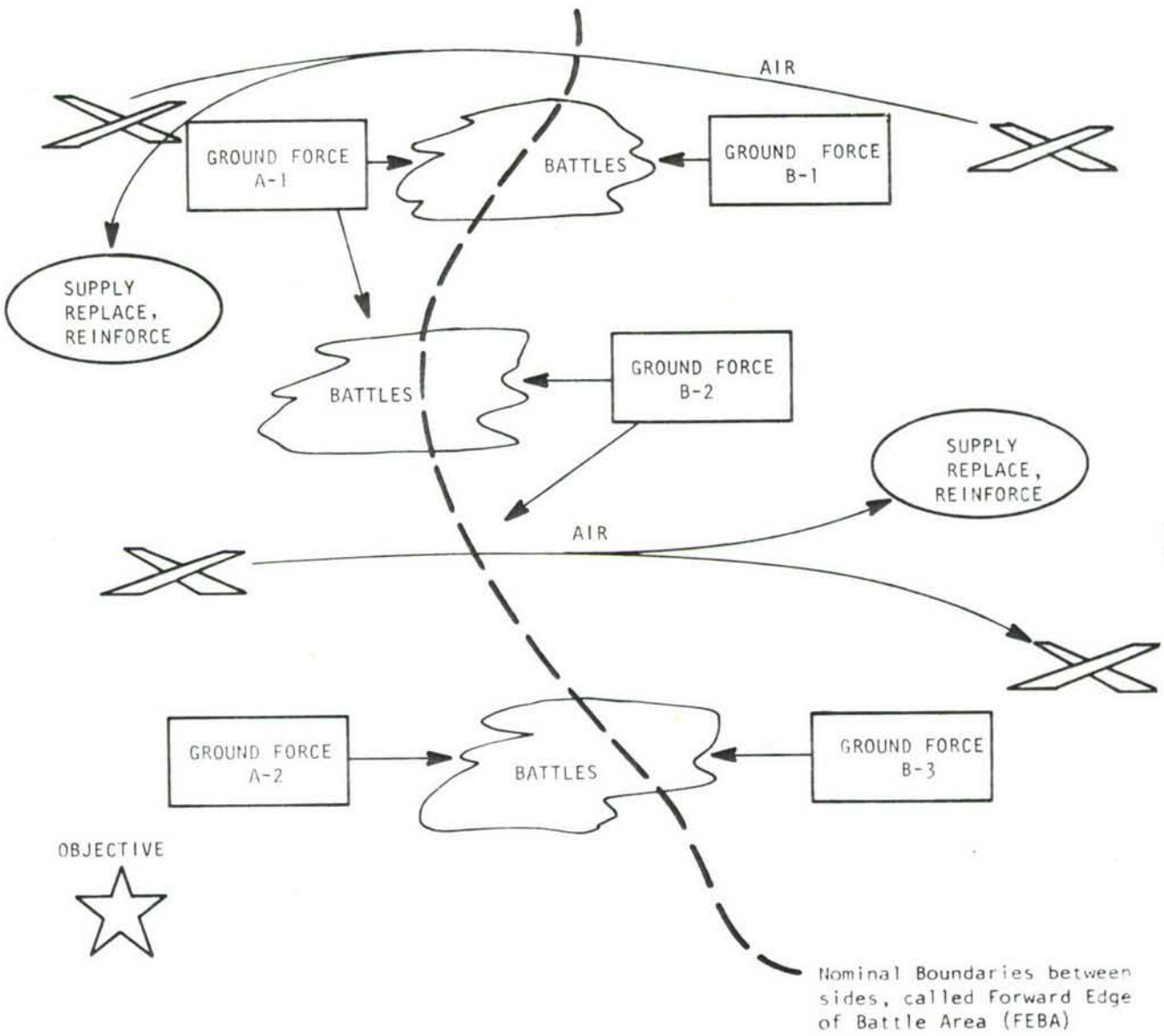


Figure 4. Elements of Theater Level Interactions

Both opponents have a wide range of choices for ground and air forces, which it is highly desirable to account for in models. Unfortunately, this is extremely difficult to do because of the large number of systems involved and the wide variety of options available for their employment. There are no models that can handle all the possibilities on a one-for-one basis. Consequently, the models at theater level, like those at global level, have been developed to use aggregate MEI to account for collective properties of the forces involved. Said another way, the theater level models assess the total impact of a number of battles occurring at different times and places throughout the theater, and the battles are modeled in terms of MEI. The modeling of the interactions between the MEI is done in the battle level models.

The dialectical nature of the modeling hierarchy is evidenced by the fact that most theater level models include battle level subroutines. One may thus wonder why the battle level is included as a separate hierarchical level. The reason is to underscore an important conceptual point. The battle level is where the modeling interactions between physical things cease, and the estimating of relationships based on indices begins.

Figure 5 illustrates this important conceptual point. Some MEI are developed at the encounter level, and passed along with other relevant information to the battle model. In the battle model, movement rates, casualties, etc., are computed on the bases of relationships between the MEI, as modified by the other input factors. Then the outputs of the battle level model are input to the theater level model to determine the theater wide outcome.

Examples of how the MEI are developed and processed at the theater and battle level are provided by several specific models discussed below.

One of the best known theater level models is ATLAS, developed by the Research Analysis Corporation for the Army (6). The following general description of ATLAS is taken from Reference (6).

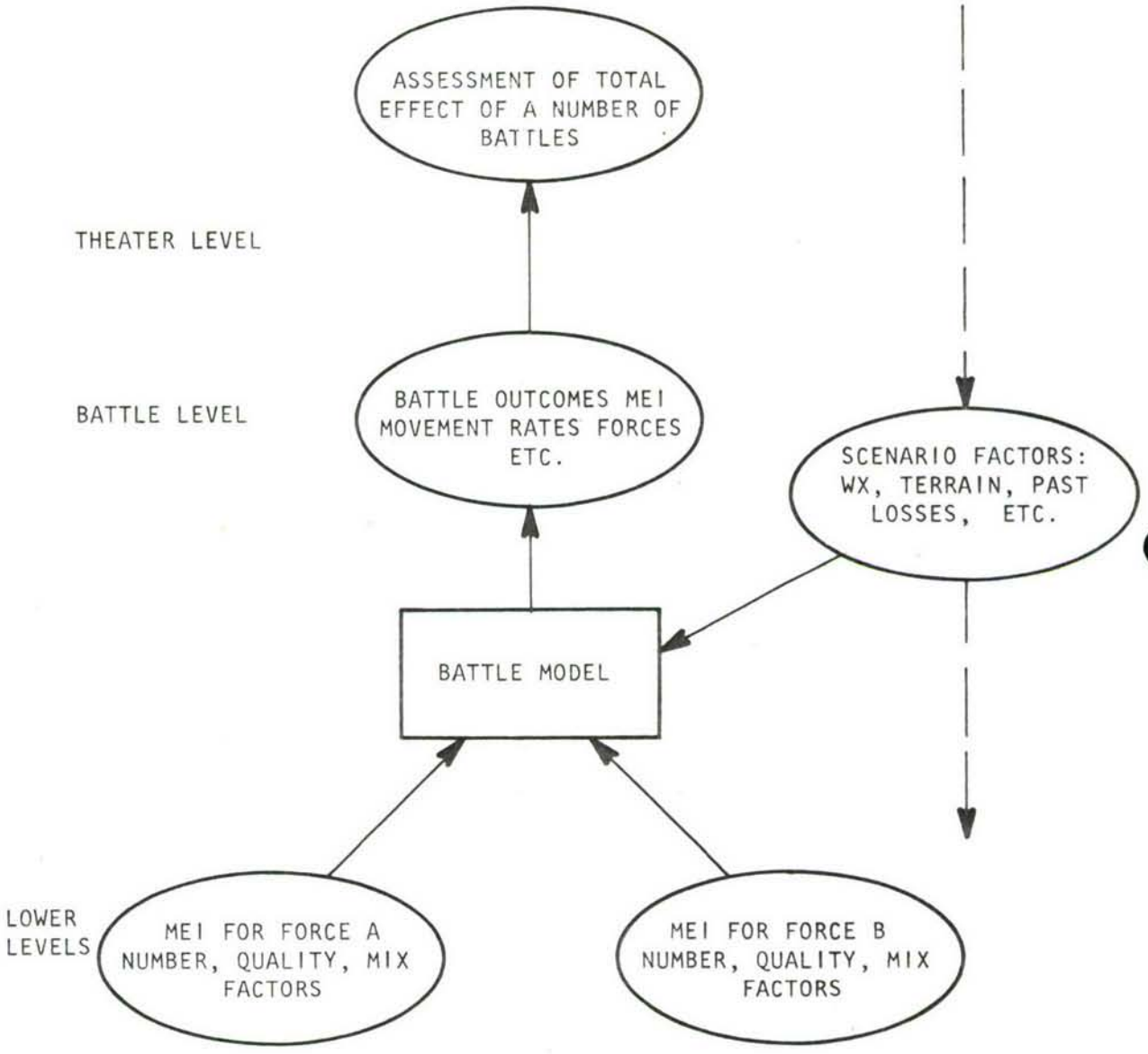


Figure 5. Conceptual Role of the Battle Model

"ATLAS, a theater-level combat simulation (model), is an operations research technique for determining the effectiveness of combat forces in a theater combat environment. The simulation can be played in either a requirements or a capabilities mode. By successive iterations, ATLAS can estimate either the theater force required and the times that reinforcing units must arrive in theater to hold an enemy at a given defense line or the force required to seize an objective. In the capabilities mode, ATLAS can be used to estimate when and where a given force deployed over an indefinite period will stabilize the enemy's advance.

. . . . . .

ATLAS is essentially a planner's war game. From a theater viewpoint it encompasses most of the parameters of combat operations at about the same level of detail as would be available in theater contingency planning. However, the game operator should not try to resolve combat operations to a finesse not warranted by the game structure. If specifics on tactics, weapons, or organization are required it will be necessary to use a more deliberate lower (sic) resolution war game . . . .

To apply ATLAS to a given combat environment, the theater of operations is divided into battle sectors as shown in Figure [6]. The sectors extend from the rear areas of one force through the theater to the combat area and into the rear areas of the opposing force. Sectors correspond to axes of advance or withdrawal and vary in width from the frontage required for a division to that required for a U. S. corps. Within each battle sector the terrain is classified as to its suitability for military operations, and any militarily significant barriers or prepared defensive positions are so designated. Ground lines of communications (LOC) are laid out in each sector and supply points or nodes are established along the LOC. Existing air bases and aerial-transport landing fields are associated by sector with the nearest supply node."

The battle model subroutine of ATLAS operates independently in each sector. The role of MEI is as follows. In each sector the force size, composition and relevant capability measures are combined into a MEI referred to as the Fire Power Potential (FPP). The FPP of a single weapon is essentially the product of the lethal area of each round of ammunition available for that weapon, multiplied by the number of rounds available for expenditure in one day. The FPP for a unit is obtained by summing over all weapons types, and the FPP for a sector is the sum of all unit FPP in the sector. Thus all weapons, munitions, and units

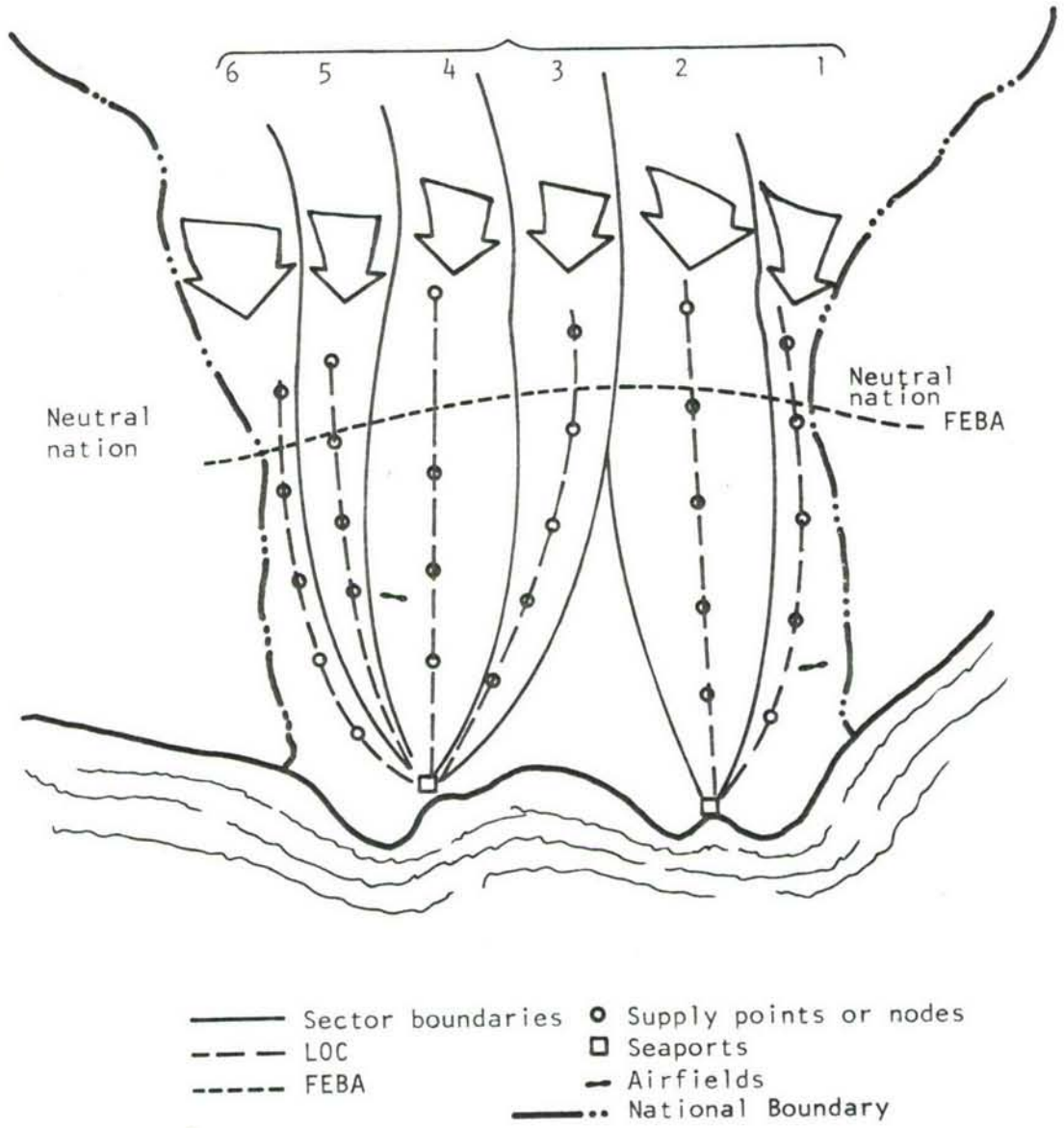


Figure 6. Schematic Representation of Theater of Operations As Modeled by ATLAS[1]

[1] Extracted from Reference 6

are aggregated into one MEI for each sector, the FPP.

The battle portion of ATLAS modifies the FPP to account for personnel losses, replacements and supplies. The modified indices are referred to as Indices of Combat Effectiveness (ICE). Then the battle model computes a rate of FEBA movement and personnel casualties on both sides based on ratios of the ICE. Account is taken of which opponent is on the offense, and the degree of preparation of the defender.

One way to visualize the battle model of ATLAS is to imagine that in each sector the opponents are separated by a flat wall. Pressure on each side is represented as the ICE of the sector. The pressure ratio, in the form of the ratio of the total ICE of each side, modified for attack and defense, determines the rate of movement of the wall. The forces of each side do not mix. The forces in one sector do not mix with those in another sector. To emphasize, it is stated again that the model does not relate directly to physical things, but to the ICE, and the dynamics are based on estimated relationships between the ICE that are built into the model.

It is interesting to compare the way ATLAS uses MEI to the way conceptualized in global models. The global models operate on a variety of strategies, each of which has a payoff specified by a complex MEI that accounts for a multiplicity of force interactions, national objectives, and values. The game solution to obtain an optimum strategy is relatively simple, but the MEI are extremely complex. In fact no useful MEI has been developed for this purpose.

In comparison, ATLAS operates on a most simple MEI that is essentially just a sum of munitions multiplied by their lethal areas. ATLAS attempts to accommodate the complexities of the scenario in the modeling, not the MEI. There are significant questions, however, as to how adequately combat factors such as FEBA movement and casualties can be related to such simple indices as FPP or ICE. The following comments are taken from reference (6).

"In ATLAS the battle assessments are primarily dependent on the numerical values of the firepower available to the opposing forces. Those firepower values are modified by personnel losses or by inadequate supplies to form an ICE. Undoubtedly in actual combat valid ICEs do exist at any given moment in time. However, if they could be calculated they would be the result of a whole spectrum of conditions that determine combat effectiveness. At the present state of gaming, weapon firepower effects are assumed to be linearly additive with no enhancement (or degradation) included as a result of combined weapons effects. It is recognized that in real combat pervasive factors such as training, morale, combined arms, and command and control often play a dominant role. However, in force planning it is unwise to attribute these tenuous factors to one side or the other. The actual conditions of possible combat are unknowable at the lead time at which the force planner works. Therefore the planner must emphasize in his analysis those combat factors that he can control or that are calculable. Thus the expression of average expected results based on comparative modified firepower scores can be misleading, or even wrong, unless all the other important ingredients of battlefield success are essentially in balance.

This caveat is equally applicable to other war games and is only included here because the deterministic character of ATLAS seem to favor precise conclusions without qualification. On the other hand it can be argued that ATLAS avoids some of the hazards inherent in using firepower scores for small-unit actions because it aggregates to brigade - or larger - sized units and finally to sector totals. As the size of the force increases, many of the crucial determinants of small -unit success such as leadership and luck tend to balance out. Thus when well-trained and adequately supported forces are pitted against each other the force ratios calculated from firepower are more likely to be the dominating factors in determining larger-unit success."

The points quoted are still very much in debate in the analytical community. Continuing attempts are being made to construct MEI and models that include the "important ingredients of battlefield success," and what is more fundamental, to find out what these ingredients really are and how they can be quantified.

Two limitations of ATLAS as a theater model, independent of the quality of the MEI, should be noted. First the model does not invent and operate a variety of strategies for each opponent. Strategies must be invented by the analyst and input manually. Strategies within a corps are essentially limited to specification of reserves. In addition,

since the sectors are independent, there are no flanking movements, no envelopments, and no crossing of sector lines. Sector combat is not influenced by the state of the battle in adjoining sectors.

These restrictions on movement are partially alleviated in the TOTEM-TALLY methodology of Rand (7). TOTEM is a ground battle model and TALLY is an air allocation and air battle model. In TOTEM, the theater is modeled as a checkerboard, usually with each square 10 km. on a side. Ground units can be deployed and employed according to selected strategies within the theater. The strategies are selected by judgment and input to the model. Results of combat and movement rates are determined by MEI which are computed for each square in the checkerboard. Rand usually operates the model with FPP/ICE, although other indices may be used provided appropriate movement, casualties, etc. can be estimated in terms of the indices.

The air model, TALLY, provides for various air allocation strategies, also selected by judgment and input to the model. On the basis of the specified allocations and the numbers of aircraft available after accounting for drawdown due to attacks by enemy air, a number of aircraft are made available for combat air support. The effect of combat air support is coupled to the ground battle by counting the number of specific targets killed by air and subtracting the value of these targets from the MEI for the appropriate square where the combat took place. This model has the means for relatively detailed assessment of the impact of weather on TAC AIR, and can also account for interdiction, attacks on enemy airfields, and air-to-air combat.

TOTEM and TALLY produce time traces of FEBA movement, casualties, and drawdowns of equipment that appear to be intuitively reasonable, although it is difficult to put confidence bounds on the results. As in ATLAS, there are MEI employed to determine a combat result, except in TOTEM the index is applied over the forces in a relatively small square rather than in corridors roughly perpendicular to the FEBA. A significant limitation

is that the strategies are input by judgment and it is not feasible to examine all the possible strategies that one opponent might use to counter an advantage on the other side.

Strategy variation is important in theater level assessments of force capability. One model developed for that purpose is TAC CONTENDER (3). TAC CONTENDER is a game-theory model along the lines proposed by Pugh. The details are not important for this paper, but the nature of the MEI used and the concept and limitations of the model are interesting.

The primary MEI in TAC CONTENDER is a very simple quantity referred to as Tons of Combat Air Support (TCAS). This measure is calculated by summing up the weight of ordnance that could be delivered by aircraft of a particular force to support the ground units of that force.

The model addresses air forces only. Each opponent has strategy options of how to allocate aircraft among the missions of airfield attack, airfield defense, battlefield defense, and combat air support. For a given air force in a theater, averages are developed for effectiveness in attacking airfields, effectiveness in air-to-air combat, and losses. Also, average munitions load carrying capacity is calculated for each aircraft allocated to combat air support. (These averages are all secondary MEI).

In the battle portion of the model, the aircraft are engaged in the various missions according to the strategy selected, losses of each side are computed, and the number of tons of ordnance delivered to support the ground forces by aircraft allocated to that mission is calculated. This is the primary MEI, TCAS.

The reason TCAS is the primary MEI is this: the strategies of each side are chosen by the model, and the solution of the game is the particular set of strategies that, if played over the time period of the game, would "optimize" the TCAS of each side. "Optimize" means that each side attempts to keep the difference between its TCAS and the opponent's TCAS as large as possible.

Figure 7 below is taken from typical results of the model and illustrates why strategy variations should be considered. The points in the figure,

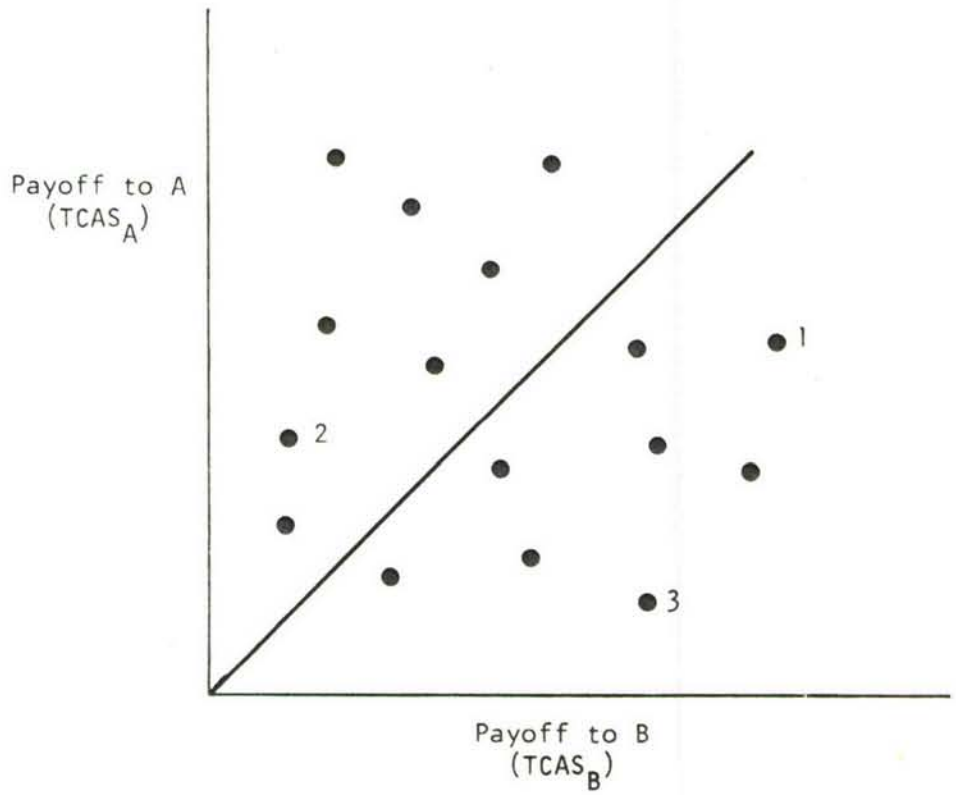


Figure 7. Possible Outcomes from an Air Battle Model[1] When only A and B Air Allocation Strategies are Varied (A Time Period of Several Days is Employed in the Model.)

[1] From TAC CONTENDER(8)

except number 3, relate to specifically constrained strategies. For point number 1, the strategies were constrained to combat air support throughout the conflict period. B has a larger force with more load carrying capacity and anti-aircraft defenses were approximately equal, so that B simply carried more weight to the ground forces.

For point number 2, B was constrained to allocate to combat air support only, but A was free to attack B's aircraft. During the course of the battle over a period of several days. A killed most of B's aircraft, and A had time and aircraft remaining with which to deliver a relatively substantial tonnage to support A's ground forces. Point 3 illustrates the strategy where both air forces are free to allocate so as to maximize their TCAS minus the opponent's TCAS. Here B does relatively well, but A does poorly.

The above example, though illustrative only, points out the great dependence of the effectiveness assessment of strategy. It is believed that this dependence is fundamental and real, so that some account must be taken of it in a model.

TAC CONTENDER, like ATLAS, uses a very simple MEI. The drawback is that the TCAS has not been related to the ground force battle in any way. The air model is optimized separately from any ground actions, and the effect of the TCAS on the FEBA movement, ground casualties, etc. is not considered.

In an effort to extend the capability to allow for air and ground strategy variations on the part of both opponents, research is underway by the Assistant Chief of Staff for Studies and Analysis, USAF with a methodology for solving a game with several variables and strategies. The technique called DYGAM has been adapted to some theater-level combat siutations where both air and ground interactions are considered; but, to date, only air strategies have been allowed to vary. Therefore, there is still no integrated model that varies both air and ground strategies to obtain an optimum at theater level.

The DYGAM research indicates that the fundamental problem with strategy-varying theater level game models is similar to that of global games. There is no lack of capability to specify relevant processes and describe these in mathematical detail. The problem is the number of possibilities that must be considered. In a coupled ground-air battle model at the theater level, with adaptive, interactive strategies, the number of variables is enormous. Computing machines are inadequate to handle this problem. Therefore, to limit the number of variables and strategies, extremely aggregate MEI are required.

The MEI developed to date are basically averages that do not permit resolution of force mix problems.

The above examples were for relatively complex and detailed theater-battle level models. The next two examples show models developed at the theater-battle level with emphasis on as much simplicity as possible. These are not intended to replace the detailed models, but are supplements and controls.

The Lanchester Square Law is a simple model proposed, among others, by F. W. Lanchester during World War I (9). While a very large number of extensions of the theory have been proposed (see Lanchester references), the simple square law forms the basis for a number of battle models in use today. The model also illustrates an MEI with implications that have become part of the conventional wisdom over the years.

The basic idea of the square law is that the casualty rate over time of a force is directly proportional to the number of enemy engaged. This is modeled mathematically by equations such as:

$$1.\quad \frac{dA}{dt} = -E_B B \quad \text{and} \quad \frac{dB}{dt} = -E_A A$$

where E_B is "effectiveness" of B expressed as number of A killed per unit time per unit of B's force, and E_A is the "effectiveness" of A defined analogously. Assuming E_B and E_A do not change with time, these equations can be solved to show that any time:

2. $E_B (B_0^2 - B^2) = E_A (A_0^2 - A^2)$

where B_0, A_0 are the initial forces, and B, A are the remaining forces.

Equation 2 is sketched in Figure 8 below for three relationships between E_B, E_A, B_0, A_0. Note that if E_A/E_B is less than B_0^2/A_0^2, then A will draw down much faster than B. If E_A/E_B equals B_0^2/A_0^2, then the forces will draw down at the same rates. They may then be said to have parity according to this model. For example, if B has twice the number of forces as A, then A must be four times as effective as B in order to maintain parity. The ratio of E_B/E_A, or its inverse, is a MEI usually referred to as the Ratio of the Lanchester Coefficients, and the rule of thumb is that the square of the ratio of forces required for parity is equal to the Ratio of the Lanchester Coefficients. Another MEI which is a measure of relative strength is $E_B B_0^2 / E_A A_0^2$. If this index is greater than one, then B is "stronger" than A, because A will draw down faster.

There are several serious problems with these equations that will be obvious to the reader. How is "effectiveness" for a total force to be determined? How do the components of individual weapons combine? What about terrain, weather, acquisition, and other effects? Should the coefficients change with time and if so, how? As indicated by the large number of references, there have been many efforts to extend this theory over the years including probability formulations and others.

One approach suggested by Grubbs and Shuford (10) is to recast equation 1 in the following form:

3. $A/A_0 = e^{-at^x}$; $B/B_0 = e^{-bt^y}$

where a,b,x,y are statistical parameters and t is time. The idea is to set up detailed models of specific weapons systems, or perform specific tests to derive the values for a, b, x, and y. With these values the drawdowns of A and B could then be calculated at any time in the battle model using equation 3. This is an interesting approach. One suspects the problem will be to extrapolate a,b,x,y outside the limits of the detailed

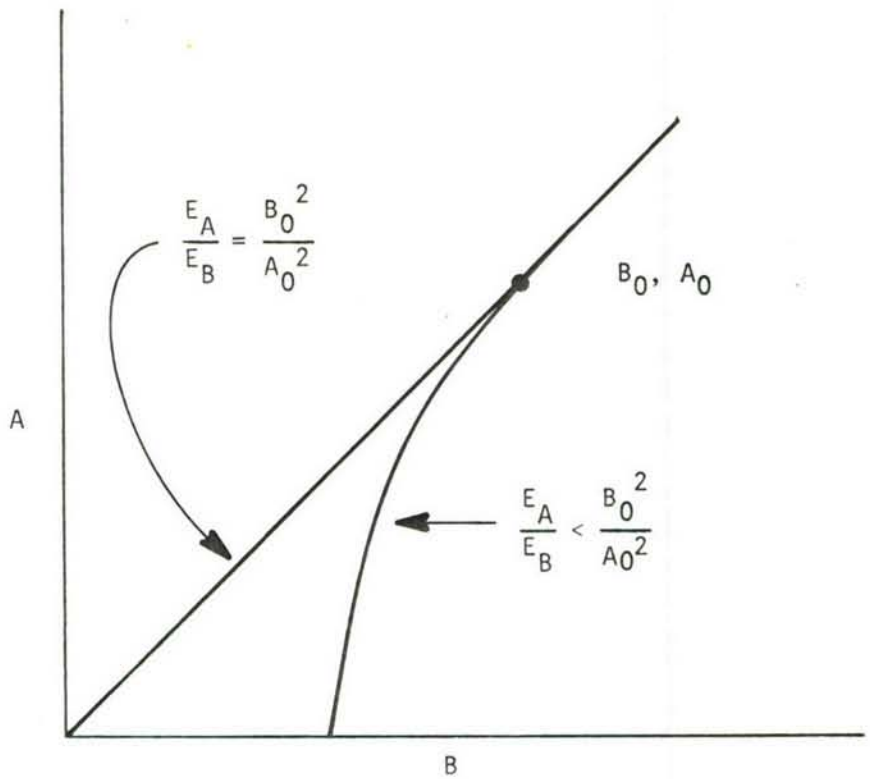


Figure 8. Typical Lanchester Square Law Drawdowns

scenario modeled or tested. Changes in the composition of the force are likely to be troublesome, but at least it's a step forward.

An interesting approach to extend the Lanchester Equations has been suggested by Albinia and Markham (11) working under the auspices of WSEG/IDA. No name was proposed for the new approach, but for brevity it will be referred to herein as the Fraction of the Front Dominated (FFD).

This methodology develops two kinds of indices: a force strength ratio; and the fraction of a line of engagement (front) over which a given value of the force strength ratio could be maintained. The force strength ratios are derived from Lanchester Equations similar to equation 1 above, except that a term for aircraft attacking ground forces is added. Special restrictions are that the aircraft themselves are not attrited, and there are two separate forms for the equations. One form is applied to ground forces subject to attrition from aimed fire weapons, such as tanks. The other form of the equation applies to ground forces subject to attrition from area fire weapons, such as personnel. The methodology does not allow these two kinds of forces to be considered together.

The specific Lanchester equations are beyond the scope of this paper. Their solution is analogous to equation 2 above. However, where equation 2 implies the relative strength ratio $E_B B_0^2 / E_A A_0^2$ between homogeneous forces, the new formulation allows for non-homogeneous forces by providing separate terms in the strength indices for air and ground forces. The new indices also include a factor to account for the advantage of defense for one side or the other. With these additional terms, the new relative strength ratios are referred to as S_t and S_p for ground systems attrited by aimed fire and for personnel, respectively. The factors in these strength ratios are summarized in Figure 9 below.

S_t or S_p may be compared directly for two forces. Suppose this is done at the theater level, and suppose that S_t for A relative to B is 2. This can be interpreted to mean that, by this measure, A is twice as strong as B over the entire theater front. However, making the comparison

S_t and S_p are ratios of the relative strengths of opposing forces.

S_t is used for ground systems that are attrited by aimed fire. For example, tanks.

S_p is used for ground systems attrited by area fire. For example, personnel.

S_t and S_p include factors that account for:

Numbers of systems involved

Kill rates of systems

Effect of attack/defense posture

Effect of air or ground based systems

Figure 9. Relative Strength Indices Used in the FFD Methodology

over the entire front does not account for the opponents' options for localized massing of forces and options for allocating air to support the ground forces. Therefore the methodology was extended to account for these strategy variables.

The extension proceeds as follows. Suppose B is the defender. It is assumed that B has no knowledge of the location where A might attack and that B chooses to deploy ground forces uniformly. Thus if one considers a continuous portion of the front representing some fraction, f, of the total width of the front, the number of B ground forces assigned will be fB.

A does not necessarily choose to deploy ground forces uniformly. Since A can compute B's force at f, A can mass his total force so as to achieve a high strength ratio (value of S_t or S_p) over f. Of course A must also account for the strength ratio over the rest of the front. In the methodology, a value is chosen for the strength ratio that A desires to achieve over the massing region f. This desired strength ratio is referred to as Z. Over the rest of the front, A is assumed to desire a holding position with S_t or S_p equal to one.

If there were no air forces on either side, the methodology would proceed as follows: B would deploy uniformly. A would choose a value of Z for the desired strength ratio over the massing region. Then, A would divide his force so as to mass and obtain Z over the region f, with a strength ratio equal to one over the rest of the front. For any total force A, and any Z, there is a maximum value for f, which is the maximum fraction of the front that A could dominate. This is how the index accounts for deployment of ground forces. This is not quite the final index desired, however, because the air forces have yet to be considered.

The air forces are considered by creating a game similar to that described for global models and TAC CONTENDER. Of course both B and A can affect the strength ratios of S_t and S_p anywhere along the front by varying the air allocation. However, to make a solution possible it is assumed that air allocated to the massing region f is applied uniformly over f, and the air allocated to the remainder of the front is also applied uniformly.

Thus, the game strategies for A and B are the fractions of the total air available that are allocated to f. The game is played with A attempting to allocate air so as to maximize f, and B attempting to allocate air so as to minimize f. The maximum value of f finally obtained through this process is the Fraction of the Front Dominated (FFD).

There are a number of significant limitations of the FFD approach, most of which were noted in the description. To summarize, the method requires separate treatment of forces such as personnel and tanks. Air forces are not attrited. The defender must deploy uniformly. Air is applied uniformly within that portion of the front to which it is allocated. In addition, there is a problem of adding air to ground in a single equation that gives proper account of differences in targeting, acquisition, and modes of employment. However, no other model has solved that problem satisfactorily either.

On the other hand, the FFD is a very simple dynamic model that, while very approximate, might be useful as a control or comparison to more complex and detailed models. At the very least the FFD is a good example of a fresh look at the problem.

To sum up the theater level models, there are none known to this observer which keep detailed track of individual items such as riflemen, or artillery tubes, or individual tanks, or even individual units such as battalions. Such a level of detail is impossible because of the numbers of specific items involved and because of the extremely large number of possible situations that could involve each specific item. All the theater models use some type of aggregate MEI and relate theaterwide results to the outcomes of battles fought in terms of the MEI.

A major problem with theater models, as integrators of a number of battles spread over distance and time, is that strategy variations must generally be input manually by the analyst and optimal strategies are not usually determinable. The models that optimize strategies require MEI that are so highly aggregated that force-mix trades are not feasible.

The battle level models, where the movements and losses are derived from relationships between the MEI, are often contained within the theater level models as subroutines. Sometimes the battle level models may be operated directly at the theater level. The Lanchester Equations can be operated at theater level directly or at a lower level.

The problem with the battle level is that the outcomes of combat between highly diverse types and numbers of weapons systems is much more complex than the relatively simple estimates based on MEI that are employed in the battle models. It is thought that important aspects of the weapons system and scenario are lost in the battle level aggregation.

The above points clearly spotlight the dilemma in dynamic modeling. The theater level models need highly aggregate MEI so that strategy variation and optimization may be considered. Yet these aggregate MEI mask the individual differences between weapons, and even units. Furthermore, scenario dependent information is lost in the aggregation. As a result trades between mixes of forces, especially disparate systems such as aircraft and tanks, are not possible with the present state of the art.

D. ENCOUNTER, ENGAGEMENT, OPERATIONS AND ENGINEERING LEVELS

In general the outputs of the encounter level are some sort of MEI that can be used in battle level models. In many cases, however, such as the calculation of Fire Power Potential, the modeling of the encounter is suppressed, and the index is simply calculated in the battle model according to some rule. Implicit in this, however, is the assumption that the MEI represent some kind of effectiveness in the encounter. On the other hand, there are battle level models that do use a scenario dependent MEI developed in an encounter model. In addition there are many encounter models operated for direct information.

Despite difficulties in specifying relevant possibilities and details, the encounter and lower level models are on sounder ground than the battle and theater models because physical interactions can be modeled directly at the encounter and lower levels. These levels will be dealt with briefly, and as a group.

A portion of the Saber Armor Methodology (12), (13), (14) illustrates the engineering, operations, engagement, and encounter levels. In this methodology aircraft are compared in the close air support mission. The methodology begins with basic engineering data such as engine thrust, fuel, consumption, wing lift and drag data, weights of the aircraft and munitions, etc. This is the engineering level. Then these data are input to a series of mathematical models that calculate turn performance, climb rates, take-off rolls, range, payload, and loiter information and so forth. This is the operational level. Given the operational performance capabilities of the aircraft, assessments are made in other models of the capabilities of the aircraft to attack certain types of targets, one at a time. Also calculations are made to assess the survivability of the aircraft against specific kinds of antiaircraft defenses. These models are at the engagement level. The outputs of the engagement levels are the familiar P_k, or probability of killing a specific kind of target on a single pass, and the P_a, or probability of attrition on a single pass. These engagement-level assessments include all the tactics that can be modeled. The results of the engagement models are input to the encounter models. At this level the extrapolation is made from a duel with a particular target or attritor type, to an encounter with a variety of weapons systems, targets, and defenses, all operating in combination. In the Saber Armor methodology, this is done with the TAC SUPPRESSOR model. Outputs of TAC SUPPRESSOR are MEI referred to as average numbers of Targets Killed per Sortie and average number of Aircraft Lost per Sortie. These MEIs are input to the battle model used in the Saber Armor methodology, and they can be used in other battle models such as the battle subroutines of TOTEM-TALLY. The primary limitation of these MEI is that they are developed in such detail that they are extremely scenario dependent. When the scenario or strategy in TOTEM-TALLY is varied, the MEI may no longer be appropriate, so that a complete rerun of the Saber Armor methodology may be needed. This is a painstaking, time-consuming process.

To sum up the engagement and lower levels, there is a break here from the battle level. The lower level models are used to compare specific weapons systems, and they are relatively detailed and complete. They have MEI as outputs, and possibly as inputs, but these are more physical MEI such as take-off roll or loiter time rather than something conceptual such as Fire Power Potential. Thus the encounter and lower levels are of lesser interest in this paper dealing primarily with aggregate MEI. A few comments were provided primarily for perspective.

The major problem with the encounter and lower level models is that they are so extremely scenario dependent that it is impossible to generalize their results.

E. RECAP OF THE DIALECTICAL HIERARCHY AND THE ROLE OF MEI IN DYNAMIC MODELS

The above sections discussed the concept of a dialectical hierarchy of models and showed that MEI are necessary to represent aggregate force capabilities in dynamic models. In general the decision maker and analyst must be keenly aware that no model or methodology can be expected to predict real world outcomes at any level. There are too many variables, too many tactics, too many employment strategies, and too many natural unknowns (such as weather) to enable deterministic predictions. The models are comparative rather than predictive.

On the other hand, models and methodologies are often useful for comparing specific alternatives with specific constraints. Here it is well to remember that the higher the level of analysis chosen, the less the detail that can be obtained on specific weapons types and specific units. The very greatest care must be taken when aggregating detail into MEI to be processed at a higher level. Ideally the decision maker should know what is being aggregated at each level and be able to believe that the transition from one level to another is valid for his particular problem.

Because of the loss of identity of detail in the aggregation process, it is desirable to have some kind of rule of thumb to aid intuition and to assist in validating results of the dynamic models. This is one of the

factors motivating interest in MEI in their own right. The idea has been to attempt to compare MEI directly to assess force capabilities without going through the dynamic modeling processes. This is called a static use of MEI, or the MEI used this way are often referred to as static or potential indicators. These are discussed in the following section.

CHAPTER III
STATIC USE OF MEI

A. CONTRAST BETWEEN DYNAMIC AND STATIC USE OF MEI

The difference between dynamic and static use of MEI follows. In dynamic comparisons the MEI are employed in models such that the numbers of participants, locations, and perhaps effectiveness, change with time. The model outcomes for each opponent are compared at various times. In concept the MEI or the combat relationships derived from theory are highly scenario-dependent. In contrast, for static use only a starting condition is examined. No "game" is played with the static index.

The same index might be used both dynamically and statically. For example, ATLAS uses the FPP as a dynamic index to determine FEBA movement and casualties as a function of time. If desired, the analyst could interrupt the dynamic sequence at any given time and attempt to predict the final outcome from the current ratios of the FPP. Obviously, the longer the dynamic game is allowed to run, the closer the prediction would agree with the final outcome. On the other hand, the earlier a good prediction could be made the greater the savings in computational time and expense.

The interesting general question of static indices is how well the static measure taken at the beginning of the game compares to the final outcome. Can a static measure be derived which indicates the same relative effectiveness as a dynamic model? Can this be done ex-ante, i.e., before the dynamic model is operated? Can an index be derived with sufficient generality that it can serve as an approximate comparison to help validate or short cut detailed dynamic models? These questions are examined in the following sections.

The discussion proceeds by examining the features of some representative static MEI. This list is illustrative only, but references are provided for those interested in further research.

One semantic point is noted before proceeding. The static MEI are usually compared in the form of ratios of MEI for one opponent versus the other. In fact, static MEI are often referred to as relative force effectiveness indices to connote the comparison by ratios. In this paper the term static MEI may mean the individual MEI of each opponent, or the ratio of the individual MEI, depending on the context. This should not cause confusion since the context should be clear.

B. REVIEW OF REPRESENTATIVE STATIC INDICES

1. Inventory Count

This is the most simple and straightforward index. However, its use as an MEI is by no means trivial because it has both a definite utility and a significant danger of misuse. The utility is derived from the inherent simplicity of the inventory count. The indices are simple sums of numbers of items, and the numbers are easy to see and check. Therefore the inventory count can be used for comparison to more complex and detailed indices whose conceptual and methodological bases may be more obscure. If a highly complex index shows a relative effectiveness much different from that indicated by the inventory count, a flag should be raised in the mind of the analyst or decision maker. Differences should be reconciled in terms of factors that were included in the detailed index but excluded in the inventory count. Thus the inventory count, if properly used, provides some protection from nonsense indices that are not understood.

On the other hand, the inventory count can be easily misinterpreted if used as the sole basis of comparison. Inventory ratios have little meaning when comparing mixes of weapons unless one compares numbers in distinct classes, and the classes are very similar. Counting of unlike military units can be particularly misleading. For example, a U.S. armored division has almost the same number of tanks as a Soviet tank division, but about twice as many men, and over three times as many rifles, and so on for other weapons. So on what basis is one armored division comparable to one tank division? Nevertheless, one hears and reads of comparisons based solely on numbers of divisions. The point is that the inventory count should always be used, but it should almost never be used alone.

Another term sometimes heard is "division equivalents." This term can be misleading too unless one knows the basis of equality that is assumed. This is usually some MEI such as Fire Power Potential (FPP) which is discussed below.

2. Index of Combat Effectiveness and Fire Power Potential

The Index of Combat Effectiveness (ICE) is the aggregate index that is used in the ATLAS model described in the previous section on dynamic use of indices. The following is quoted from reference (6).

> "The measure of combat effectiveness used in the model is called the ICE, a number that purports to indicate the worth of a combat unit in comparison to some standard unit. The ICE. . . . are derived from more fundamental numbers called Firepower Potential Scores (FPS). By knowing the lethal area of a type of round of ammunition (given as a function of personnel posture) and multiplying by an assumed daily expenditure rate for this type of ammunition, there results a Firepower Potential Score in terms of a lethal area per day. When each of the Firepower Scores for all the weapons of the division have been added and then normalized about the FPS of the standard unit, the result is the ICE for the unit considered."

In the dynamic model ATLAS the ICE are modified for combat factors, terrain, casualties, etc. as described previously. The Firepower Potential Scores (FPS) used to derive the ICE have evolved to a measure now in vogue called Fire Power Potential (FPP). The FPP are essentially products of rounds fired per day and lethal areas per round fired, normalized to an anti-personnel basis. The FPP are expressed symbolically in Figure 10 below.

Examination of Figure 10 reveals two classes of quantities; those involving counting or counting estimates (ammunition expenditure, numbers of weapons in a unit), and those involving relationships between the type of ammunition and personnel targets. The counting estimates are straightforward. The relationship of area ammunition to personnel targets is expressed by the mean lethal area. The relationship between point fire weapons and personnel targets is more subtle. It has two components: the probability of a mobility or fire power kill of a target susceptible to

$$\text{WEAPON FPP} = \Big[\overbrace{\left(\begin{array}{c}\text{EXPECTED}\\ \text{EXPENDITURE OF}\\ \text{AMMUNITION BY}\\ \text{WEAPON}\end{array}\right) \times \left(\begin{array}{c}\text{MEAN LETHAL}\\ \text{AREA OF}\\ \text{WEAPON}\end{array}\right)}^{\text{Anti-Personnel Effectiveness of Area Fire Ammunition}}$$

$$+$$

$$\text{CORRELATION FACTOR} \times \overbrace{\left(\begin{array}{c}\text{EXPECTED}\\ \text{EXPENDITURE OF}\\ \text{AMMUNITION BY}\\ \text{WEAPON}\end{array}\right) \times \left(\begin{array}{c}\text{AVERAGE PROBABILITY}\\ \text{OF A MOBILITY OR}\\ \text{FIREPOWER KILL BY}\\ \text{WEAPON}\end{array}\right)\Big]}^{\text{Equivalent Anti-Personnel Effectiveness of Point Fire and Anti-Armor Ammunition}}$$

$$\text{UNIT FPP} = \sum_{i=1}^{\text{NUMBER OF WEAPON TYPES}} \left(\begin{array}{c}\text{WEAPON}\\ \text{TYPE } i\\ \text{FPP}\end{array}\right) \times \left(\begin{array}{c}\text{NUMBER OF}\\ \text{WEAPON TYPE } i\\ \text{IN UNIT}\end{array}\right)$$

Figure 10. FPP Equation

point fire weapons (such as a tank), and a correlation factor which converts the kill of such a target into an equivalent anti-personnel lethal area. How well are these FPP relationships known?

Lester and Robinson (15), in a review of the FPP[1] indicate that mean lethal areas of area type weapons against personnel are adequately known. However, they state that there are significant uncertainties in relating the lethalities of point fire and anti-armor ammunition or weapons to personnel. Sufficient data is lacking. Consequently, relationships between probabilities of killing targets such as armor and personnel lethal areas are based largely on judgment.

They point out that to the extent this judgment is based on experience or gaming that reflects the opportunity for engagement, command and control, mobility and other relevant factors, the judgment could compensate for the omission of combat factors in the index. On the other hand, it is impossible to know what factors are included by judgment and to what extent.

Another difficulty with the FPP is that the index is linear in that it does not exhibit diminishing marginal returns as weapons are added. The 10,000th weapon of an opponent adds exactly the same measure to the total index of that opponent as does the 10th weapon, and this does not seem reasonable.

A limitation of the FPP is that it does not lend itself to inclusion of TAC AIR. There is such a great disparity between mobility of aircraft and ground based weapons systems, and differences in modes of employment, targeting, acquisition and so forth, that most professionals seem to agree that air and ground weapons cannot be meaningfully mixed in the FPP/ICE.

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[1] Lester and Robinson examined the ICE/FPP, and several other indices, some of which will be discussed below, on the basis of dependence on historical data, judgment, comprehensiveness, linearity, and applicability to TAC AIR.

3. Personnel, Tank, Shelter and Based Aircraft Attriting Potentials

Four measures have been employed separately by WSEG/IDA (16), (17) to avoid the correlation factors inherent in FPP type indices. In this way forces can be compared on the individual bases of Inventory, Personnel Attriting Potential (PAP), Tank Attriting Potential (TAP), Shelter Attriting Potential (SAP), and Based Aircraft Attriting Potential (BAAP). The forms of these indices are shown on Figure 11 below. Except for the PAP, the details of the calculations of the indices are classified. The PAP is shown in Figure 12.

Note that these indices are maintained separately for air and ground weapons systems. This is a disciplined approach which avoids aggregating disparate weapons in the absence of a reasonable conceptual basis. On the other hand it precludes comparison of forces on the basis of a single index. Whether or not this is a limitation of the methodology, however, is a controversial subject because there are many who contend that the nature of military effectiveness requires that a multi-index comparison be used. More will be said about this later.

In their present form, the PAP and TAP are linear in the same sense as the FPP, in that additional units contribute a quantity to the index that is independent of the absolute number of units already in the force.

4. Weapons Effectiveness Indicators and Weighted Unit Values

Much of the following section is taken from the review by Lester and Robinson, edited for brevity.

The term Weapons Effectiveness Indices or WEI originally referred to the relative values of weapons, within weapon families, developed by STAG for Task 1 of the 1971 Selected Analysis called NATO Combat Capability. These were quality factors and did not pretend to represent actual relative combat capability. Before these could be used in force comparisons, a relative value of the key weapon in each family had to be determined. These were estimated by STAG in the summer of 1971. The

Personnel Attriting Potential (Ground-Generated or Air Delivered)

The potential of ground - or air-delivered weapons to incapacitate personnel in the combat area by indirect area fire.

It is the potential fraction of the enemy personnel in combat units that the weapons of the opposite side's forces could potentially incapacitate in a day against a target base of personnel, 1/3 standing, 1/3 prone, and 1/3 in foxholes at a concentration corresponding to a division (16,000 personnel) occupying a 20 km x 30 km area. It is measured in enemy personnel incapacitated per day divided by the total number of enemy personnel in theater.

Tank Attriting Potential (Ground-Generated or Air Delivered)

The potential of ground - or air-delivered weapons to kill enemy tanks in the combat area.

It is the potential fraction of the enemy's medium tanks, standing in the open, that the weapons of the opposite side's forces could incapacitate in a day by inflicting a mobility or firepower kill. It is measured in enemy tanks killed per day divided by the total number of enemy tanks in theater.

Shelter Attriting Potential

The potential of an air force to destroy an opposing air force's shelters.

It is the potential fraction of the enemy's aircraft shelters killed (collapsed) in one day when the air force of the opposite side strikes the enemy's airfields. It is measured in enemy aircraft shelters killed per day divided by the total number of enemy aircraft shelters in theater.

Based Aircraft Attriting Potential

The potential of an air force to destroy an opposing air force's aircraft that are on the ground.

It is the potential fraction of the opposition's aircraft on the ground that are destroyed beyond repair (K-Kill) in one day when one air force, unopposed by air defense, strikes the opposition's air fields. It is measured in aircraft killed per day divided by the total number of the opposition's aircraft in theater.

[1] Extracted from Reference 16, 15

Figure 11. Forms of MEI Used by WSEG/IDA[1]

GROUND-GENERATED

- THE PERSONNEL ATTRITING POTENTIAL (PAP) FOR A SPECIFIC WEAPON TYPE IS DERIVED AS FOLLOWS:

  - FOR EACH TYPE OF AMMUNITION EXPENDED BY THIS WEAPON.

$$\begin{pmatrix}\text{LETHAL AREA PER DAY}\\ \text{PER AMMO TYPE}\end{pmatrix}=\begin{pmatrix}\text{EXPENDITURE PER DAY OF}\\ \text{THIS AMMO TYPE PER WEAPON}\end{pmatrix}\times\begin{pmatrix}\text{LETHAL}\\ \text{AREA PER ROUND}\end{pmatrix}$$

  - ADD THESE QUANTITIES TO GET LETHAL AREA PER WEAPON PER DAY THEN,

$$\begin{pmatrix}\text{LETHAL AREA}\\ \text{FOR THIS WEAPON TYPE PER DAY}\end{pmatrix}=\begin{pmatrix}\text{NUMBER OF THIS}\\ \text{TYPE OF WEAPON}\end{pmatrix}\times\begin{pmatrix}\text{LETHAL AREA}\\ \text{PER WEAPON PER DAY}\end{pmatrix}$$

- ADD THESE QUANTITIES FOR ALL WEAPON TYPES TO GET TOTAL GROUND-GENERATED LETHAL AREA PER DAY

- $\text{PERSONNEL ATTRITING POTENTIAL} = \begin{pmatrix}\text{TOTAL LETHAL AREA}\\ \text{PER DAY}\end{pmatrix}\times\begin{pmatrix}\text{TROOP}\\ \text{DENSITY}\end{pmatrix}\div\begin{pmatrix}\text{ENEMY PICU}\\ \text{TOTAL}\end{pmatrix}$

AIR-DELIVERED

- THE PERSONNEL ATTRITING POTENTIAL FOR A SPECIFIC AIRCRAFT TYPE IS DERIVED AS FOLLOWS:

  - FOR EACH TYPE OF MUNITION CARRIED BY THIS AIRCRAFT,

$$\begin{pmatrix}\text{LETHAL AREA}\\ \text{PER SORTIE}\end{pmatrix}_{\text{MUNITION TYPE}}=\begin{pmatrix}\text{QUANTITY OF THIS MUNITION}\\ \text{TYPE PER SORTIE}\end{pmatrix}\times\begin{pmatrix}\text{LETHAL}\\ \text{AREA PER UNIT}\end{pmatrix}$$

  - ADD THESE QUANTITIES TO GET TOTAL LETHAL AREA PER SORTIE; THEN,

$$\begin{pmatrix}\text{LETHAL AREA FOR THIS}\\ \text{AIRCRAFT TYPE PER DAY}\end{pmatrix}=\begin{pmatrix}\text{SUSTAINED RATE}\\ \text{OF SORTIES PER DAY}\end{pmatrix}\times\begin{pmatrix}\text{NUMBER OF GROUND-}\\ \text{ATTACK AIRCRAFT}\\ \text{OF THIS TYPE}\end{pmatrix}\times\begin{pmatrix}\text{TOTAL}\\ \text{LETHAL AREA}\\ \text{PER SORTIE}\end{pmatrix}$$

- ADD THE LETHAL AREA PER DAY FOR EACH AIRCRAFT TYPE TO FIND TOTAL AIR-DELIVERED LETHAL AREA PER DAY

- $\text{PERSONNEL ATTRITING POTENTIAL} = \begin{pmatrix}\text{TOTAL LETHAL AREA}\\ \text{PER DAY}\end{pmatrix}\times\begin{pmatrix}\text{TROOP}\\ \text{DENSITY}\end{pmatrix}\div\begin{pmatrix}\text{ENEMY PICU}\\ \text{TOTAL}\end{pmatrix}$

[1]Extracted from reference 15

Figure 12. Equation for Personnel Attriting Potential Used by WSEG/IDA[1]

WEI, when weighted by the family weights, were called combat worth (CW). When they were summed for the weapons in a unit, the resulting unit score was called a Weighted Unit Value, or WUV.

All of the weapons considered were divided into classes according to general functions and characteristics; for example man-portable small arms, APCs, tanks, anti-tank weapons, etc. A standard weapon was identified for each family. For each family, a set of dominant characteristics was defined. For example:

a. Small Arms:
   - rate of fire
   - range
   - reliability
   - portability
   - signature
   - versatility

b. APCs:
   - firepower
   - mobility
   - survivability
   - troop capacity

c. Tanks:
   - firepower (F)
   - mobility (M)
   - survivability (S)

For each weapon, the WEI was defined as a weighted sum of the dominant characteristics. For example in the case of tanks:

$WEI = W_1F + W_2M + W_3S$ where the weights (W) are determined by a Delphi technique. Next a set of factors were defined to describe each dominant characteristic. For example in the case of tank firepower, some of the factors are:

- lethality (L)
- ammunition type available (A)

auxiliary weapons of the tank (W)

etc.

Each of these factors is quantified on a 0 - 1 scale for each type of tank considered and a ratio is formed between each weapon and the standard weapon of the family. The firepower is a weighted sum of these ratios. Again taking tank firepower as an example:

$$F = X_1 \frac{L}{L_S} + X_2 \frac{A}{A_S} + X_3 \frac{W}{W_S} + \text{Etc.}$$

where the subscript denotes the standard weapon.

The weights X_i are again judgmental. The formula and weights for other weapons and characteristics can be found in STAG's report on Selected Analysis Task 1, June 1971.

Aside from the significant judgmental factors required to obtain a WEI for each individual weapon, Lester and Robinson point out that the most difficult and crucial parts of the problem are relating weapons within a single family and relating families of weapons to obtain values that can be summed to unit values (WUV). They state that there is a wide difference between analysts as to what these family weights should be. In fact, some analysts assert that dollar cost should be a good reflection of relative value. Army and OSD organizations have each developed separate weighting values which lead to separate WUV. A comparison between these will be shown later.

The above discussion makes it clear that while the WEI/WUV use identifiable and (possibly) precisely quantifiable characteristics, in all important respects the method is judgmental.

Lester and Robinson have comments on comprehensiveness, applicability to TAC AIR, and linearity of WEI/WUV. They state that the WEI consider many more weapons characteristics explicitly than the FPP, but not the relative amounts of ammunition available. The WEI/WUV are constants which are independent of force posture. The same assumption as that for FPP applies: the model in which the MEI are used must account for employment factors. On TAC AIR they say:

"The relative effectiveness of various aircraft might be stated in a Weapons Effectiveness Indicator type number. One could write expressions for clearly identifiable characteristics like range, payload, maximum or cruise speed, maneuver-ability, operating altitude or other factors and assign relative weights to them. The values chosen would necessarily be for a specific class of mission, for example, close air support. They would involve assumptions about command and control systems, e.g., are the aircraft being brought into the battlefield area under the aegis of a Forward Controller (FAC) or not; are they being held in the area on loiter or on alert status from a forward airstrip? The parameters of speed and radius of action of the aircraft have their primary significance outside of the battlefield area and affect the ability to effectively allocate firepower to critical areas of the FEBA. The meaning of the "mobility" terms are thus entirely different from those included in the expressions for tanks or mobile artillery pieces where the mobility terms in the equations express battlefield mobility.

The firepower deliverable by aircraft could, by some imaginative process, be normalized to that of a 155mm howitzer or to a tank, but there would be no accounting for the flexibility of aircraft, the difference in command and control, target acquisition, etc. The relationships derived would depend strongly on the situation or scenario, the time relationships chosen, etc. It would completely overlook the other applications of aircraft to air defense, counter-air, interdiction, and battlefield support missions and the contribution that these functions can have on the outcome of the total conflict. These Weapons Effectiveness Indicators have been used in some Army analyses to compare the relative merits of different weapons of the same general type. They have been introduced into the ATLAS models in lieu of firepower scores for ground weapons. In this latter case, they do not appear to have overcome some of the limitations of the firepower score although the relative weightings of different weapon types may permit a more interesting representation of the forces."

5. Quantified Judgment Method, Theoretical Weapon Lethality Indices, and Operational Lethality Indices

The WEI/WUV were stated to depend primarily on judgment. There are those who contend that judgment is the best approach to assessing force effectiveness. The penultimate of this approach appears to be the Quantified Judgment Method (QJM) and its associated indices. The following is extracted from the Lester-Robinson review. A comparison of the indices developed by this method and other indices is shown later.

"The QJM has been proposed by its originator, Col. T. N. DuPuy, as a general method of interpreting historical data and of predicting the relative performance of current or future forces. The basic approach is to define a set of potential capability scores for weapons (Theoretical Weapon

Lethality Indices) and then develop a number of weapon and force modifiers which will bring predicted outcomes into reasonable agreement with the observed outcomes of a large number of historical battles. Having tuned the model equations and modifiers in this way, one can then supposedly introduce current or future weapons characteristics and predict the outcome of hypothetical future battles. Theoretical Weapon Lethality Indices (TLI): The TLI's for hand-carried or crew-served weapons are:
TLI = sustained rate of fire x target density x kill probability x effective range x accuracy x reliability, where target density is taken as 1 man per 4 sq. ft.
For mobile weapons:
TLI = sum of TLI for individual weapons on vehicle x mobility factor x radius of action factor + the vulnerability factor, where mobility factor = 0.1 x cross-country mph and radius of action is cross-country distance allowed by a tank of fuel. Vulnerability is defined as "the lethality of the most effective opposing weapon that has not more than a 50% probability of incapacitating the vehicle with a single hit." It should be noted that the TLI are theoretical or ideal measures of capability.

Operational Lethality Indices (OLI): The TLI are brought up to date by dividing them by a dispersion factor that relates average modern density on the battlefield with the 1 man per 4 sq. ft. density that is supposedly characteristic of the pre-Roman phalanx. For World War II armies the dispersion factor is 3,000. For nuclear scarred forces it may be several times this. The TLIs divided by the dispersion factor are the CLIs.

Calculating Relative Combat Power: The Weapon Effectiveness of a force is simply the sum of the CLI of all its weapons multiplied by terrain, weather, season and air superiority factors as appropriate. Infantry weapon CLIs are multiplied by just a terrain factor; artillery CLIs are multiplied by terrain, weather, season and air superiority factors; armor CLIs are multiplied by terrain and weather factors and close air support CLIs are multiplied by terrain, weather, season and air superiority factors. The application of these factors change the "Weapon Effectiveness" of a force into the "Strength" of the force. The Strength is multiplied by a series of operational variables to produce the "Combat Potential" of the force. These variables are: mobility, leadership, training, morale, logistics, posture, vulnerability. Some of these are considerably more complex than the weapons factors. For example the mobility factor affecting the attacking force is

$$m_a = M_a - (1 - r_m \times h_m)\ (M_a - 1)$$

Where:

r_m = terrain factor affecting mobility
h_m = weather factor affecting mobility

and

$$M_a = \frac{N_a + 20\ J_a + Wi_a \times My_a/N_a}{N_d + 20\ J_d + Wi_d \times My_d/N_d}$$

Where:

N = personnel strength
J = number of trucks
W_i = armored firepower
M_y = air superiority factor affecting mobility
a = subscript for attacker
d = subscript for defender

The definition of the other operational variables can be found in Col. DuPuy's paper entitled "The Quantified Judgment Method of Analysis of Historical Combat Data" of 3 May 1972.

The ratio of the Combat Potential of the friendly force to that of the enemy force is the measure that supposedly determined the theoretical winner of the battle: If this ratio is greater than 1, the friendly force should win in the sense of achieving its objectives; if it is less than one the friendly force fails. As mentioned before the TLI and OLI are very theoretical and arbitrary in nature. The weapon and force modifiers attempt to add more realism by considering, explicitly, various factors that may have a considerable effect on the outcome but that are not usually included in force comparisons. The problem is, of course, to be able to define these factors. Col. DuPuy's approach is to define a measure of outcome for actual historical battles and adjust the weapon and force modifiers until the actual outcomes and the predicted outcomes agree a large proportion of the time--in the sense of the outcomes being in the same direction, but not necessarily to the same degree. There is no rigorous procedure for doing this in the QJM; i.e., no regression or other statistical analyses are applied. The factors are adjusted by trial and error with judgment applied to the extent possible. No tests have been conducted to determine the uniqueness of the combination of factors finally determined nor which are the most important factors. Another fundamental difficulty is that many of the operational variables cannot be predicted for a future battle or imply the context of a detailed game that generates terrain, weather, air, logistics, and posture situation. If one assumes average conditions for both sides, the QJM, to a large extent, reverts to a simple comparison of theoretical weapon scores. It should be noted that the QJM is now designed for division level comparisons and therefore it could help in the comparison of large forces only through a game or simulation that uses something like ICE."

6. Combat Effectiveness Index (CEI)

The CEI is an approach outlined by Fallon (16). He began with the proposition that the effectiveness of any weapon in combat can be described in terms of: a) the quantity of ordnance required to achieve a specified probability of kill; b) the time to achieve this kill; c) the normal logistics associated with the necessary ordnance; d) the cost to achieve

the kill; e) mobility, or system ability to respond dynamically. Expressions for each of these terms are proposed, and a form of index combining the factors is presented.

The number of rounds to achieve a specified kill probability is derived from the standard assumption that each round is delivered independently, so that $P_k = 1 - (1 - P_{ss})^n$ where P_k is the overall probability that the target is killed, P_{ss} is the probability that any single round would kill the target if no other rounds were involved, and n is the total number of rounds delivered on the target. For any specified P_k this can be solved for n:

$$n = \text{logarithm } (1 - P_k) \;/\; \text{logarithm } (1 - P_{ss})$$

The minimum time to achieve the specified P_k using a single weapon system operating at its maximum firing rate is assumed to be:

$$t_k = n / E_m$$

where E_m is the maximum rate of fire, and t_k is the minimum kill time.

Fallon states that logistics constraints often prohibit weapons from operating at maximum fire rates for significant periods of time. Consequently, he defined another kill time referred to as logistic kill time:

$$t_s = n / E_s$$

where E_s is the normal sustained rate of fire.

The minimum kill time and the logistic kill time are combined as follows:

$$t_{ks} = (t_k \cdot t_s)^{\frac{1}{2}}$$

where t_{ks} is the geometric mean kill time to achieve a specified P_k.

The cost factor is assumed to be as follows:

$$C_k = t_s \cdot C_t + P_L \cdot C_I + nC_r$$

where C_k is the cost to achieve a specified kill probability; t_s is the logistic kill time; C_t is the average cost of ownership of the weapon system per unit time based on a ten-year period; P_L is the probability of loss of the weapon system in achieving the kill; C_I is the initial cost to replace the weapon system; C_r is the cost of a single round of munition; and n is the number of rounds to achieve a specified kill probability.

To derive a factor for mobility it is assumed that the worth of a weapon's mobility is proportional to an area it can cover, modified by a response effectiveness factor.

The area covered is assumed to be:

$$A = R \left(R/2 + 2V\, t_o \right)$$

where A is the area, R is the range of the specific munition considered, V is the velocity of travel of the weapon system and t_o is the time period that the weapon system can operate

The response factor is assumed to be:

$$M = e^{-t_2 / L}$$

where M is response effectiveness. The symbol t_r denotes the time for the weapon system to move from its location to the target location, plus the time to acquire and attack the target until the specified kill probability is achieved. The symbol L denotes the target lifetime.

With the above factors defined, Fallon postulated an index referred to as the CEI with the following form:

$$CEI = h\, M\, C_k^{-a}\, t_{ks}^{-b}\, A^c$$

where CEI is the index; h is some proportionality constant , M is the response factor; C_k is the cost factor; t_{ks} is the time factor; A is the area factor; and a, b, c are each positive numbers whose actual magnitudes are not defined. Fallon states that since there is no obvious analytical way to determine values for h, a, b and c, they will all be set equal to unity. Then the final index is:

$$CEI = M\, C_k\, t_{ks}\, A$$

A number of difficulties with this index are well-known to Fallon and others, and it is not proposed for wide use. However, its inclusion in this paper is not for the purpose of criticism, but to point out the extreme difficulty of including scenario-dependent detail in any static MEI developed for general applicability.

To illustrate, consider the expression for the time factor:

$$t_{ks} = (t_k \cdot t_s)^{\frac{1}{2}}$$

Fallon notes the problem of defining this factor as follows:

"These times, t_k and t_s, represent two very important aspects of any weapon system. Clearly, a weapon that can inflict damage on a target rapidly and continuously is more valuable than one that can inflict the same damage much more rapidly but very infrequently because of logistics constraints. Thus the weapon with the lower mean kill time should be considered more effective. An arithmetic mean of the maximum kill time and the logistic kill time would give very little credit for rapid delivery. This is not the case with a geometric mean which can accomodate large variations."

The validity of this statement is strongly scenario-dependent. One reason is that the importance of killing a target quickly depends on the rate the target can inflict damage, the lifetime of the target, and the frequency that such a target is likely to appear. If the target appears infrequently but must be killed quickly (an enemy missile in launch configuration, for example) then the logistics kill time is not useful, and its inclusion distorts the index. On the other hand, an area weapon such as artillery used as continuous disruptive fire should be measured on the basis of logistic time.

Scenario factors are also evident in the mobility factor, where target life and response time are obviously scenario-dependent. The cost factor includes the probability of loss, which is clearly scenario-dependent.

Thus, the CEI illustrates the fundamental logical antinomy of attempting to define a static, scenario-independent MEI that includes all the relevant factors and detail that discriminate weapons systems. If the detail is included, then the scenario must be considered. If the scenario is excluded, then the detail cannot be meaningfully included. It cannot go both ways.

7. Comparability of Static MEI

Quite likely the previous sections have demonstrated that the possibilities for defining MEI are almost unlimited. It seems reasonable to suggest that the very large number of attempts is due in part to

dissatisfaction with existing options, and in part to attempt to capture different parts of the total comparison problem with MEI specialized for specific comparisons.

Certainly to attempt to compare many MEI under controlled conditions would be an exhausting task. The comparisons would probably be most meaningful if the MEI were designed to measure the same things. For example, two MEI designed to estimate tanks killed per sorties should be comparable. If they contain the same factors they should agree exactly or should be traceable to input data or formulation.

Differences in input data should be resolvable. Differences in formulation may not be. If the indices do not agree because of differences in formulation, there may not be any way to determine which is "right." In the absence of an objective test, both indices, which may show significantly different results, are likely to be used in practice. On the other hand if two indices do agree closely, why keep both in service?

At any rate, the most useful comparison of static MEI probably is that which was done in the previous sections to compare the factors considered and the nature of the formulation. Of course for actual force level comparisons, the indices should be studied in complete detail, not just in form.

Some attempts have been made to validate static MEI through comparisons to dynamic model outcomes. This might be useful if the model is built reasonably independently of the MEI. But if the model is built on MEI similar to the one being checked, the result may be circular. For example, ATLAS is built on FPP which are built on lethal area and rounds per day. To compare ATLAS to an index like PAP or TAT, which are also built on lethal area and rounds per day, may be questionable. It seems that at best one would get a difference due to maneuver, casualty rates, and other factors built into ATLAS but absent in FPP. But how large should these effects be? If the outcomes are different, are they due to these differences? If the outcomes are similar, does it mean that the dynamic factors are not important, or does ATLAS mask the dynamics in the aggregation process?

The previous paragraphs argue that direct comparisons between MEI are difficult, to say the least. Therefore, it is logical that those interested in making force comparison, should turn to the practice of presenting these comparisons on the basis of several indices rather than on just one or two. Both WSEG/IDA and SAGA have adopted this philosophy in recent studies. Security classification prevents direct reproduction of study results, but certain relative results derived from a study by Thomas and Anjier of SAGA (19) are presented below to give the reader a feel for the comparability of FPP, WEI/WUV, TAP and OLI.

Figure 13 below extracted from the Thomas-Anjier study, shows differences in characteristics of the four MEI. Recall that the WEI/WUV and OLI make the additional assessments on the basis of judgment. It will be seen that these indices vary from the other two, and from each other.

Figure 14 shows the ratios of the MEI for three particular tanks. This figure illustrates two points. First the scores for specific weapons of the same type may vary widely among the indices. Second, the relative values among the indices are not preserved from weapon to weapon of a particular type.

Figure 15 shows the comparisons for a single tank and a single anti-tank weapon. This shows that the scores also vary widely when comparing weapons of different types.

Figure 16 shows comparisons for typical units and weapons within units. Note that the total unit scores show less variance than the previous scores based on single weapons. This is apparently a wash-out caused by the number of different weapons types and families. On the basis of antitank weapons alone, larger variations are seen, and on the basis of antitank plus tank plus armored vehicles the differences again become smaller.

Thomas and Anjier concluded, among other things, that no single MEI adequately considers all weapons systems attributes, and in the absence of the "right" MEI, comparisons should include several MEI. WSEG/IDA seems to agree with that point, and usually provides several measures

Characteristic	Methodology				
	FPP	WEI	WUV	TAP	OLI
KILL POTENTIAL/LETHAL AREA	X	X		X	X
AMMUNITION EXPENDITURE	X			X	X
DURABILITY/RELIABILITY		X			X
PORTABILITY/MOBILITY		X			X
SURVIVABILITY		X			
FIRE CONTROL		X			
TERRAIN					X
CLIMATIC FACTORS					X

Figure 13. Selected Weapon System Characteristics

(Considered by MEI[1])

[1]From reference 17

Ratio of Effectiveness For:	Index FPP	WEI	TAP	OLI
Weapon A / Weapon B	.89	1.0	.67	1.2
Weapon A / Weapon B	2.1	.80	4.8	.94

Figure 14. Comparison of MEI for Single Weapons of the Same Type (Tanks)*

Ratio of Effectiveness For:	Index FPP	WEI	TAP	OLI
Tank / Anti-tank Weapon	.43	.76	.09	.44

*Derived from Thomas-Anjier Study (17)

Figure 15. Comparison of MEI for Single Weapons of Different Types*

Ratio of Effectiveness For:	Index RPP	WUV(1)[1]	WUV(2)[2]	
Unit A / Unit B	.60	.52	.46	
	FPP	WEI	TAP[3]	OLI
Anti-tank Wpns of A / Anti-tank Wpns of B	.10	.20	.18	.16
Anti-tank + Tank + Armored Vehicles of A / Anti-tank + Tank + Armored Vehicles of B	.58	.76	.55	.52

* Derived from Thomas-Anjier Study (17)

1&2 Two measures of WUV based on different judgments of the value of each weapon family in the unit

3 Study used a version of TAP that did not divide by the number of tanks in the units. A correction factor has been applied.

Figure 16. Comparison of MEI for Typical Combat Units*

including inventory counts in their studies.

To sum up, answers can be given to the questions posed at the beginning of the section on static MEI. Can a static MEI be derived that approximates the results of a detailed dynamic model? The answer is perhaps, but none has been generally demonstrated with sufficient credibility to justify the index as a sole comparison. On the other hand, static MEI can be useful adjuncts to the dynamic models.

Can a static index serve as a "rule of thumb"? The answer is that no single index invented to date can be trusted as the sole indicator, but a comparison of several indices can help the analyst and decision-maker develop insight. At the present time judgment and experience remain by far the most important tools for estimating the relative effectiveness of military forces.

CHAPTER IV
SUMMARY AND SUGGESTIONS FOR FUTURE WORK

A. RECAP

Military Effectiveness Indices play a key role in the analysis of general purpose forces. Transfer of information between the hierarchies of dynamic models is accomplished through the use of MEI which aggregate the detail at one level and pass the composite information up the hierarchy. Controls and checks on detailed dynamic models are made through direct comparison of static, or potential, MEI.

There is an important difference in concept between the MEI as used in dynamic models and the static MEI. The MEI used dynamically are highly scenario-dependent in concept. The dynamic model plays out movements, losses, weather, and other operational and combat factors over time to create ever-changing scenarios. Theoretically each scenario developed in a model would call for a lower level model to create a specific MEI appropriate for that scenario. Thus both detail and large scale operations could be accommodated. In contrast, the static MEI are intended to be scenario-independent. The static MEI are supposed to indicate relative outcomes before the fact, that is, before the dynamic models are operated, and hence they must be independent of the particular scenarios that evolve over time.

Practical difficulties of current dynamic models may be framed in terms of the above concepts. Pressures from limitations of modeling theory and computational limitations have driven most higher level (theater-battle and above) models to the use of MEI that are so highly aggregated that both scenario variations and weapons systems differences are masked. Only gross size and "weight" information of the forces is maintained. Resolution is lost, so that force-mix trades are impossible. Furthermore, with the detail masked, there is no satisfactory way of checking results; therefore the overall credibility of the models has always been a matter of concern.

This does not mean that theater-battle level dynamic modeling should be abandoned. On the contrary, efforts should be redoubled to advance the capability along the lines implied by the concept noted above. The hierarchy of modeling should be adhered to. Subroutines or files that develop or maintain scenario dependent MEI should be available to the battle models so that specific scenarios call appropriate MEI. These MEI should be expressed in terms that can be understood operationally so that validation of the MEI is possible. Above all, the detail must be appropriate for the scenario, and vice versa.

The static MEI have a different purpose from those used dynamically. Since the scenario is excluded in the static comparisons, operational detail must also be omitted. The dilemma with static MEI is to invent a form that discriminates essential military characteristics without recourse to scenario dependent operational detail.

One way to do this is through the potential approach illustrated by the Tank Attriting Potential and others in which there is no postulated correspondence either to reality or to a model. The measures are simply proposed as ways of weighting numbers of weapons and ammunition. The limitation is that many weapons and target discriminates are omitted.

As the attempt is made to add characteristics, two crucial problems arise: how to determine which weapon system properties to include, and how to specify relationships among these factors for the indices. No satisfactory way of doing this has been discovered.

What of the future for static MEI? For immediate use it is suggested that a standard series of potential indicators be developed along the lines of TAP, PAP, BAAP, etc. A discipline should be developed by the agencies and analysts expert in the field. The discipline should specify which weapons to include as classes for comparison, and the classes should not be mixed, nor should attempts be made to interrelate classes. For example, tanks vs. tanks could clearly comprise one class of TAP, but a standard should be set to determine if antitank plus tank could be paired against tank, and so forth. Aircraft and ground systems must be kept separate

at the present state of understanding. No attempt would be made to relate TAP and PAP, for example.

With the standard potentials, force effectiveness would be a vector consisting of the set of relevant potential indicators. Two forces would be compared with each potential compared directly to the opponent's on a one-on-one basis. This approach has the advantage of being clear, easy to calculate and duplicate, and standard for all concerned. It provides a great deal of information to the decision maker to assist his judgment. On the other hand, the various indices are almost certain to give conflicting indications so that there is still a strong incentive to "close the problem" by weighting the indices together in some way.

B. A NEW STATIC MEI

The following is presented as only the kernel of an idea for a possible way to close the "potential" indices. It is built upon general concepts outlined by Georgescu-Roegen (1) and Harden, Eubank and Sliepcevich (20). Georgescu-Roegen wrote a topical book in which he developed the concept on entropy as a universal evolutionary law by which economic processes could be measured in principle. Harden, et al, developed a general mathematical expression that is consistent with entropy theory, and which they propose as a general measure of economic utility.

It is hypothesized now by this observer that the fundamental reason that no single measure of military effectiveness has proven satisfactory in the past is that no single global utility or value measure has been discovered. It is further postulated that the <u>relative ability to add to the opponent's entropy</u> is one such measure. With this postulate it is possible to invent a static MEI that is analogous to the measures of information content and thermodynamic free energy that are widely used in engineering.

The proposed measure:

$$S(p_i) = K_1 \ln \frac{P_1}{Q_1} + K_2 \ln \frac{P_2}{Q_2} + \ldots\ldots\ldots k_n \ln \frac{P_n}{Q_n}$$

where: Q_i are static potential measures of one opponent, and P_i are the static potential measures of the other; K_i are dimensionless weighting factors; and S is a dimensionless quantity that measures the relative force effectiveness.

Difficulties with this expression are obvious. Clearly there are no known ways to obtain the K factors. However, models might be run, or standards developed by test, judgment, or logic. A caveat is that the Q_i and P_j must be independent for all $i \neq j$. This simply means that the specification of one potential ratio cannot automatically define another ratio used in the expression. This does not appear to be a great problem.

Despite the difficulties, the S formulation has properties that are highly desirable in a force index. First, it is defined only in terms of scenario-independent potential quantities, and by using ratios the scale for comparison can be chosen arbitrarily. Second, it immediately shows overall parity by a zero value and allows marginal return computations at any level of relative effectiveness. Third it exhibits diminishing marginal returns for any factor that contributes to a particular potential. Fourth it is additive with weight K_i for any new potential.

A general formulation of an approach using this entropy measure of combat capability as a transfer between modeling hierarchies will be presented in a subsequent paper.

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TITLE: CEM* - CONAF Evaluation Model

PROPONENT: U. S. Army Combat Developments Command

DEVELOPER: Research Analysis Corporation

PURPOSE: CEM is a computerized, analytical model designed to portray the course of theatre-level, non-nuclear war in terms of FEBA location, condition of opposing forces, and expenditure of resources. The primary problem addressed is that of determining the effects of force structure on force performance in theater-level warfare.

GENERAL DESCRIPTION: CEM is a two-sided, deterministic model involving land and air forces. It is designed to consider groupings as small as a brigade on the Blue side and a division on the Red side, and can aggregate up to the level of a theater army (and air force).

Simulated time is treated on a time step basis. The model uses only basic arithmetic and logical operations as its primary solution techniques.

INPUT:

- Terrain map.
- Military objectives.
- Troop lists.
- TOEs.
- Weapon firepower indices.
- Resupply and replacement rates.

OUTPUT:

- Computer printout stating (periodic) FEBA location, state of opposing forces and resources expended.

MODEL LIMITATIONS:

- Blue brigade structure cannot be changed during a war.
- Reserve units (if any) consist of exactly one of the next lower echelon unit.
- Logistic operations highly aggregated.

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*Note that despite the similarity in acronym, this is a different model from CEM II, listed elsewhere in this publication.

HARDWARE.

- Computer: CDC 6400
- Operating System: SCOPE 3.2+
- Minimum Storage Required: 140,000 Octal 60-bit words.
- Peripheral Equipment: 2 tape drives and/or disk.

SOFTWARE:

- Programming Languages: FORTRAN IV; COMPASS (ASSEMBLY LANGUAGE)
- Both user's documentation and technical documentation are complete, and are presently undergoing review prior to publication.

TIME REQUIREMENTS:

- 2 months to acquire base data.
- 18 man-months to structure data in model input format.
- 10 seconds CPU time per twelve-hour cycle.
- 2 months to analyze and evaluate results.

SECURITY CLASSIFICATION: UNCLASSIFIED

TIMES USED SINCE 1969: Once

USERS: U. S. Army Combat Developments Command

POINT OF CONTACT: Force Structure Department
Research Analysis Corporation
McLean, Virginia 22101
Telephone: (703) 893-5900

MISCELLANEOUS:

- It is presently planned to improve the representation of logistic operations and their effects on combat capability of a force.

KEYWORD LISTING: Analytical Model; General War (Non-Nuclear); Land Forces; Air Forces; Computerized; Two-Sided; Deterministic; Time Step.

CONCEPTS EVALUATION MODEL (CEM)

1. General. - This paper is taken from a general information briefing on the Concepts Evaluation Model, commonly called CEM. The model was developed by General Research Corporation as a theater-level combat simulation to support the original CONAF Study, and in fact, was originally named the CONAF Evaluation Model. CONAF is an acronym for Conceptual Design for the Army in the Field, a planning activity for force design in the US Army. CEM is a fully automated, deterministic, event-step combat simulation that plays conventional forces at theater-level along a continuous FEBA. Its usefulness extends to any study in which the play of theater-level combat situations is desired.

A definition of terms may be appropriate before going further. As a fully automated computer simulation, CEM has no player participants. All characteristics of the physical world become part of a computer program either as program constants or inputs. In this type of model, the player's role is to supply inputs and to analyze the program results or output values. Although this type of model does not provide the player with decision-making experience, it is ideally suited to the type of analysis done here at CAA. When used as a mechanism by which pieces of comparative information can be generated, this type of model has great usefulness. If several courses of action are to be studied in a military situation, the speed with which the computer makes iterations possible allows CEM to be played over and over again with different inputs, yielding information related to each choice of actions available.

This information can then be used comparatively to determine for instance the best action in a given situation, or the best major weapons system from an effectiveness standpoint.

The deterministic design of CEM is a further benefit in the comparative use of simulation results. This feature of CEM means that successive runs with identical inputs will provide exactly the same outputs. This permits the variation of a single force characteristic (for example, the firepower of tanks) with assurance that the new battle outcome is ascribable to that change alone. As a deterministic model, the decision rules in CEM are such that each action is followed by one and only one reaction.

Combat simulations in general can be thought of as a set of actions, reactions and a series of decision rules associating each action with its appropriate reaction. There is an overriding structure which is in CEM - the simulated commander's decisions which serve to create the action-reaction chain described above.

As an event step combat simulation, CEM considers that the next event advances game time in a non-uniform manner. The assumption is apparent that nothing of importance occurs, relevant to the simulation, between events.

Time-step procedures are used when time is a continuous flow or at regular intervals.

At the present, CEM is limited to playing forces equipped only with conventional weapons along a continuous FEBA. CEM can be considered schematically (over simplified) as a box within which appropriate decision rules are followed and the computations made that result in the outputs. In other words, the player is deterministically deriving simulation outputs from the inputs to the model such as firepower scores and factors.

2. Categories of Input. Now consider the general categories and nature of CEM inputs as described in CEM:

a. Firepower: CEM uses a modified firepower score called an Index of Firepower (IFP). These IFPs are used for three primary purposes, casualty determination, FEBA movement and the decision process.

b. Battle Posture: CEM determines whether the attacker is pitted against a defender in a fortified position, a prepared position, a meeting engagement, or against a withdrawing enemy.

c. Barriers: CEM determines the type of terrain and existance of such barriers as rivers, minefields, or terrain problems.

d. Time: The time for preparation for attack or defense is determined.

e. Break Points: Various threshold values and vulnerability coefficients must be input as the basis for CEM decisions.

The following list serves to further define some major concepts as they are handled by the model.

FORCE MIX. The level of BLUE aggregation is battalion, and for RED, brigade or regiment. Within the BLUE battalion, and RED regiment, different organizations may be structured and evaluated. This capability assists in comparing varied force mixes.

LOGISTICS AND RESUPPLY. Supply is broken into three classes and maintained in pools. Low supply levels cause lowered combat power. Damaged weapons are placed in a maintenance loop and can be returned to combat. This logistics capability in the model was added in 1972 and it has essentially doubled the running time of the model.

PERSONNEL REPLACEMENT AND EVACUATION. Casualties are placed in a hospitalization cycle and a proportion are returned to duty along with new replacements coming into the theater. BLUE uses individual replacement and RED may use either unit or individual replacement. However, more realistic results are attained in the latter replacement mode.

AIR AND AIR DEFENSE. Three aircraft roles are played; interaction with air defense weapons, supply interdiction, and providing combat power to the FEBA.

ARTILLERY. Artillery is portrayed in both DS and GS roles with GS based upon the needs of the on-line units. The amount of augmenting GS fire provided as DS is controlled by a single input value. All artillery casualties are attributed to GS counter battery fire.

TERRAIN. Four terrain types may be considered. Three have an effect on firepower and mobility while a fourth, barrier terrain, causes a delay in movement of attacking forces.

DECISIONS. The decision process in CEM looks at the force available to accomplish the specified mission, compares it to the opposing force and then may allocate additional combat power, change mission, or commit or reconstitute a reserve.

One may see from this that for a theater-level model, CEM considers a multitude of variables but this is at a cost in computer and analyst's time which will be discussed later.

CEM produces FEBA locations and reports on the status of units, weapons and logistics which, at the customer's desire, may be used as measures of effectiveness. To get a feel for the number and types of units and resources played in CEM, look at the upper limits for resource definition in Figure 1. Note also the time interval for decisions at the various echelons. This reflects that a division evaluates its situation each half day (12 hours) and may then change its mission or reallocate resources. Other information here can be related to particular situations.

In CEM the battlefield is laid out in terms of lateral boundaries and types of terrain. See Figure 2. The basic lateral boundary is called the minisector. Minisectors will normally vary between one and four kilometers in width; a maximum of 1000 minisectors may be played. A subsector is defined as one or more minisectors bounded by either RED or BLUE unit boundaries. The four terrain types are determined by map

UPPER LIMITS FOR RESOURCE DEFINITION

FIGURE 1

UNITS	BLUE	RED	DECISION PERIOD
MANEUVER BN	50 TYPES	50 TYPES	
BRIGADE	150	375	
DIVISION	50	125	12 HOURS
CORPS	30	60	1 DAY
ARMY	6	12	2 DAYS
THEATER			4 DAYS
ARTY BN	8 TYPES	8 TYPES	

WEAPONS	TYPE
TANKS	12
LIGHT ARMOR	12
PERSONNEL	12
HELICOPTERS (blue only)	5
TOTAL	41

SUPPLY (TONS)

POL
AMMUNITION
OTHER

MAINTENANCE

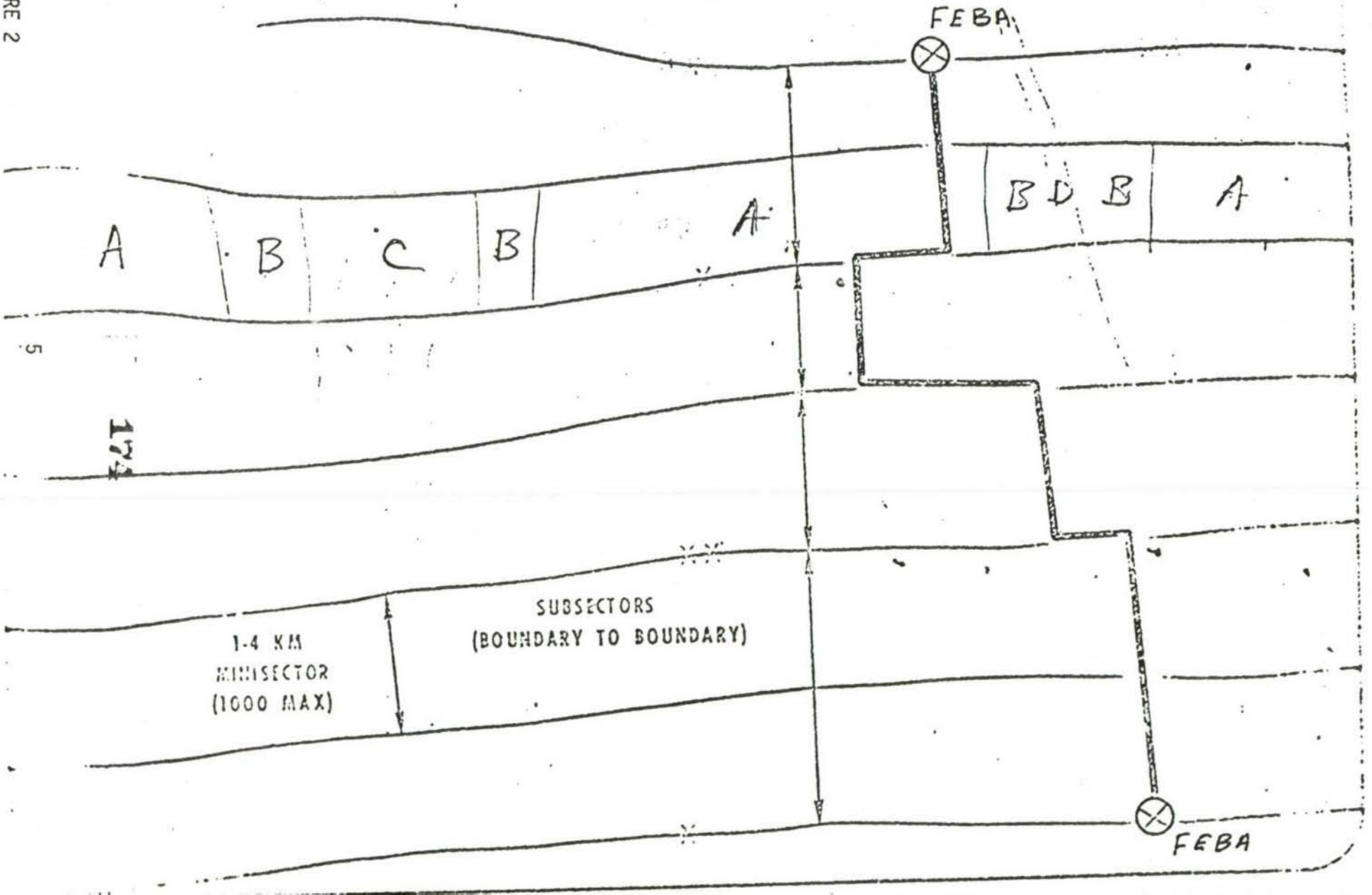
POOLS FOR
TANKS
LIGHT ARMOR
AND HELICOPTERS

PERSONNEL

POOLS WITH VARIABLE
DELAYS FOR RETURN
TO DUTY AND NEW
ARRIVALS IN THEATER

FIGURE 2

TERRAIN AND UNIT BOUNDARIES



inspection. Type A is open with good tank movement, terrain B is somewhat restricted in mobility and visibility, and on the C terrain, one is considered roadbound. The D terrain has obstacle value, whether it is a natural or man-made in nature. Combat power and mobility decrease as a unit moves from A to C terrain. On D terrain, a unit is stopped for 12 hours. If a longer delay is desired, multiple narrow bands of "D" coded terrain could be used. Since FEBA movement in the CEM is considered by subsector, an actual FEBA trace looks like the example in Figure 2. In the past, the control of FEBA movement allowed a few minisectors to penetrate 100 or 200 KM but changes made for CEM III included lateral boundary shifts to concentrate combat power against penetrations. A further refinement to CEM allows the establishment of units in reserve to rotate with weakened on-line divisions.

The minisector definitions and terrain coding are straightforward tasks but as one moves to the development of combat power, you find that CEM uses firepower potential (FPP) which must be derived for three different types of targets. These classifications are tanks, light armor and personnel. The FPP scores are modified for the type of terrain and supply shortages that may exist. The modified FPP score is called the Index of Firepower or IFP. For the purposes of casualty assessment, FEBA movement and decision the IFPs are summed into a matrix, and example of which you see in Figure 3.An IFP matrix can be built for each minisector, sub-sector or sector. Refer to "Hard vs Tank" in Figure 3. All of the hard category shooter IFPs against tank targets are summed to a value of 15. Moving down the hard shooter column, the total hard shooter IFP is 30. By summing along the row, the anti-tank IFP is found to be 75. This reflects the effect of all shooters against tank targets.

It is now appropriate to go into more detail on the primary purposes of IFPs in CEM. Let us first consider casualty determination. The basic equation used for casualties in CEM is one commonly used in wargaming models. Its general form is: casualties equal one,minus the surviving fraction where the surviving fraction is E^{-X}, which you will recognize as the classic negative exponential form of casualty equation. In relating this approach to a more specific situation, let's determine the RED tank casualties caused by BLUE. The general form of the equation is:

RED tank casualties = #RED tanks X (1-S.F.) where:

$$S.F. = E^{-\frac{\text{COEF OF DAMAGE} \times \text{AT-IFP}}{\#TANKS_R}}$$

This is shown numerically in Figure 4. Consider a RED force with 40 tanks, with a damage coefficient at 0.1. Remember our summation of BLUE anti-tank IFP is 75. This indicates that seven tanks became casualties during the 12-hour cycle. Of those seven, some are destroyed, some evacuated and some are abandoned; all those percentages used to distribute casualties are input data for the model. An identical procedure is used in handling personnel casualties in the model. Great care is required in selecting the

FIGURE 3

FIREPOWER DEVELOPMENT

THREE FIREPOWER (FPP) SCORES ARE REQUIRED FOR EACH WEAPON

- FPP AGAINST TANKS
- FPP AGAINST LIGHT ARMOR
- FPP AGAINST PERSONNEL

THE FPP IS MODIFIED BY

- TERRAIN
- SUPPLY SHORTAGE

> THE INDEX OF FIREPOWER (IFP)

CASUALTY ASSESSMENT — FEBA MOVEMENT — DECISION

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SHOOTER

TARGET	HARD	MEDIUM	SOFT	HELICOPTER (DIRECT ONLY)	ARTY	CAS	TOTAL
TANK	15	30	10	10	5	5	75
LIGHT ARMOR	10	15	10	15	10	10	70
PERSONNEL	5	15	20	5	45	5	95
TOTAL	30	60	40	30	60	20	240

FIGURE 4

CASUALTY DETERMINATION

RED TANK CASUALTIES = # TANKS × (1-SURVIVING FRACTION)
R

WHERE THE SURVIVING FRACTION =

$$e^{\frac{-\text{COEFFICIENT OF DAMAGE} \times \Sigma \text{AT-IFP}}{\text{\# TANKS}}}$$

RED TANK CASUALTIES = $\underline{40} \times \left(1 - e^{-\underline{.1} \times 75/40}\right) = 40 \times (1 - .83) = \underline{7}$

COEFFICIENT	% CASUALTIES	TANK CASUALTIES
.05	9	3.6
.10	17	6.8
.20	31	12.4

input value for the coefficient of damage because it is the single, most important variable that drives the casualty equation; further, there is no specific rationale used to derive a value, rather, a value must be selected that produces the expected results. This is normally accomplished by calibrating casualties to the results of other work. As a further numeric example of the importance of the coefficient of damage, consider what occurs with coefficients set at values of .05 and 0.2 in Figure 4. This method is used to produce both equipment casualties and personnel casualties in the CEM. The determination of FEBA movement is also dependent on IFPs. Note that artillery, helicopters and TAC AIR are not used directly in calculating FEBA movement, and although they have a long term effect on FEBA change by reducing IFP, they do not gain and hold ground. We now have derived a force ratio which, in our example, was 1.05 in favor of RED. If RED were attacking and BLUE were defending on Type A terrain, the model would look up the outcome of the battle based on the threshold value table for RED attacking a defending BLUE unit on A terrain. With a value of 1.05 (see Figure 5) we see a number three result, which in turn relates to the attacker gaining 1 KM during the division cycle. The outcome IFP ratio thresholds and FEBA movement are input data and, as with the coefficients of damage, must be input by players using high resolution results or judgment. The IFP thresholds and FEBA movement tables can drive the model. The previous example used RED attacking a BLUE defender. Other mission combinations are seen in Figure 6. A static situation occurs when opposing units are both defending or delaying; casualties occur but the FEBA will never move. Note the 8 combinations in status possible in CEM.

To determine a unit's mission and allocate combat power, the CEM operates a decision process for each division, corps, army and theater cycle. This process includes some unique characteristics compared to other theater-level models; they are intelligence, distribution of combat power, mission assignment and committing or reconstituting a reserve. Each decision level is slightly different and the following discussion covers generally how decisions are accomplished. If the GS artillery is available for a DS role, it would be committed at the higher firing rates. If the unit expects to lose, it will go to a lower order mission; for example, from defend to delay. If the unit expects a win, it will try to increase its mission or if committed, will try to reconstitute a reserve. The reserve in CEM is one of the next lower echelon. A division has a reserve brigade, the corps has a reserve division and so on. In CEM, intelligence is played as a decision-making unit using opposing information that is one cycle old. This, however, may be improved using an intelligence coefficient to increase knowledge of the current state of the opposing unit. If a coefficient of 50 percent is used, the model will split the difference between conditions in the last cycle and now, which reflects an increase in knowledge of the opposing force. For example, a BLUE IFP matrix is built using present IFP values. A RED IFP matrix is built using RED IFP values from the previous cycle. This technique gives imperfect strength figures about RED and describes how CEM considers

FEBA MOVEMENT - ENGAGEMENT OUTCOME

FOR ATTACKER VS. DEFENDER ON A TERRAIN

OUTCOME	1	2	3	4	5
IFP THRESHOLD	> 2.25	2.25-1.4	1.4-1.0	1.0-.95	< .95
FEBA CHANGE	20	6	1	0	-1

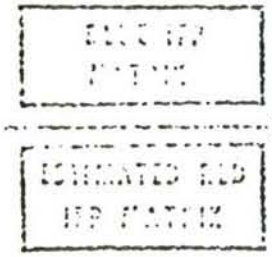
FIGURE 6

ENGAGEMENTS SIMULATED IN THE CEM

BLUE MISSION		RED MISSION: ATTACK	RED MISSION: DEFEND – PREPARED POSITION	RED MISSION: DEFEND – HASTY POSITION	RED MISSION: DELAY
ATTACK		MEETING ENGAGEMENT	BLUE ATTACK OF PREPARED POSITION	BLUE ATTACK OF HASTY POSITION	BLUE ADVANCE
DEFEND	PREPARED POSITION	RED ATTACK OF PREPARED POSITION	STATIC	STATIC	STATIC
	HASTY POSITION	RED ATTACK OF HASTY POSITION	STATIC	STATIC	STATIC
DELAY		RED ADVANCE	STATIC	STATIC	STATIC

intelligence. A BLUE division, makes decisions based upon the RED strengths 12 hours ago. Both matrices are summed and multiplied by the unit state, posture modifiers and terrain modifiers and a ratio is formed. The ratio is compared to an input table called the estimated outcome threshold table to determine the expected outcome for the situation. Three levels of response may be expected. If the answer is yes, there is no problem, but if the answer is maybe or no, the unit will search for more combat power. In its search for more combat power, it looks for what you see in Figure 7. The decision process takes place at every echelon from division and up for each cycle. The unit has made its decision - it has a mission and resources, it fights for the next cycle, is attrited as was shown earlier, and the FEBA moves. The attrition of men, weapons and supplies is replenished in CEM by using theater assets that are either prepositioned or come into theater as determined by input. Supplies are consumed and if a unit is low on supplies its firepower is degraded proportionally. For personnel and weapons, casualties are evacuated, go through a waiting period and then a portion returned to the fight. In the case of personnel, it looks like Figure 8. Input percentages will determine how many of the casualties are killed and the number evacuated from the theater, leaving a portion to return to duty. Those returning to duty go through a time-phased personnel pool which simulates some returning to duty in a few days and others over longer period. In the case of RED forces either unit or individual replacement may be used. The unit replacement technique calls for a unit to reach a state where it is considered decimated. It is then pulled out of the line and into a decimation pool. It is resupplied with theater-level assets, is given a delay time and is then returned to the line. Materiel items that become casualties are handled the same way as individual replacements except the time-phased pools are replaced with a single pool and items are not evacuated from the theater. For example, a tank casualty may be destroyed, abandoned or placed in a maintenance pool where it experiences a time delay and is then returned as a theater asset. Further, CEM allows for equipment breakdown as well as pure combat losses. All of the replacement, resupply rates and ratios are input data to the model. Restraints on theater transportation capability are introduced as time delays between the pool and a unit. Although the logistics in CEM are highly aggregated, they are logical and do have an influence on the combat power at the FEBA. A significant capability in CEM is the ability to cause lateral shifts of unit boundaries based on a function of opposing strength and differences in the FEBA location. See Figure 9. In this simplified example, note the distance "D" is measured from the rearmost FEBA location in the sector considered. The model then sums the RED unit IFP, times the distance "D", across the front and redistributes the BLUE forces so each BLUE unit faces a proportion of the RED threat as defined by the IFP times "D" function. Limitations are placed on both the maximum lateral shift per cycle and the minimum unit frontage. This feature of the model prevents unrealistic penetrations by allowing commanders to concentrate against a threatening force. These lateral boundary shifts are allowed on

THE DECISION PROCESS



- STATE
- POSTURE
- TERRAIN

COMPARE — YES-CONTINUE PRESENT MISSION
COMPARE — MAYBE
COMPARE — NO
MORE COMBAT POWER?

- INCREASED DS ARTILLERY FIRING RATE
- GS TO DS ROLE
- COMMIT RESERVE

IF THE UNIT EXPECTS A LOSS, LOWER MISSION

IF THE UNIT EXPECTS A WIN:

INCREASE MISSION——RECONSTITUTE RESERVE

REPLACEMENT POLICY

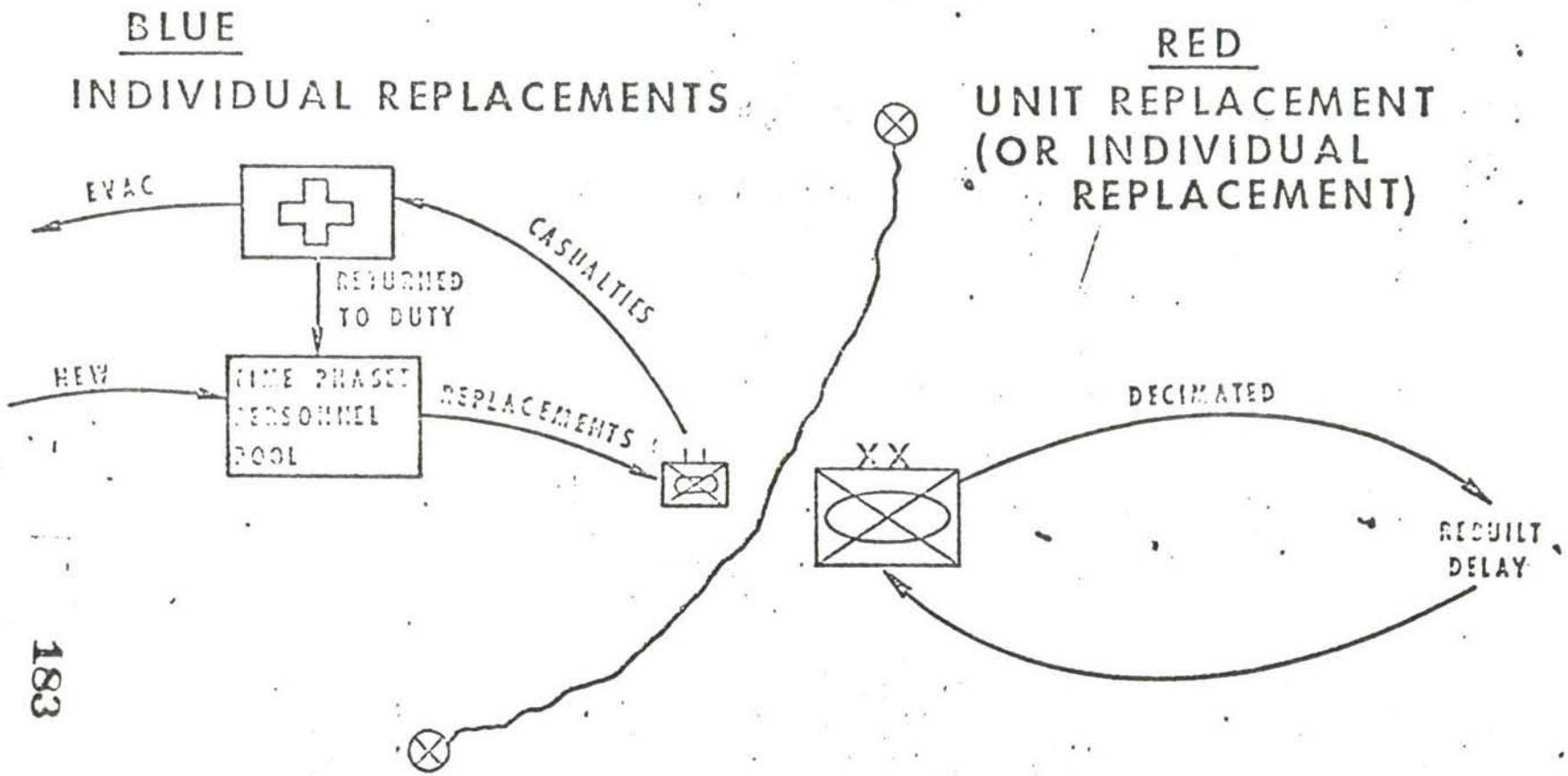
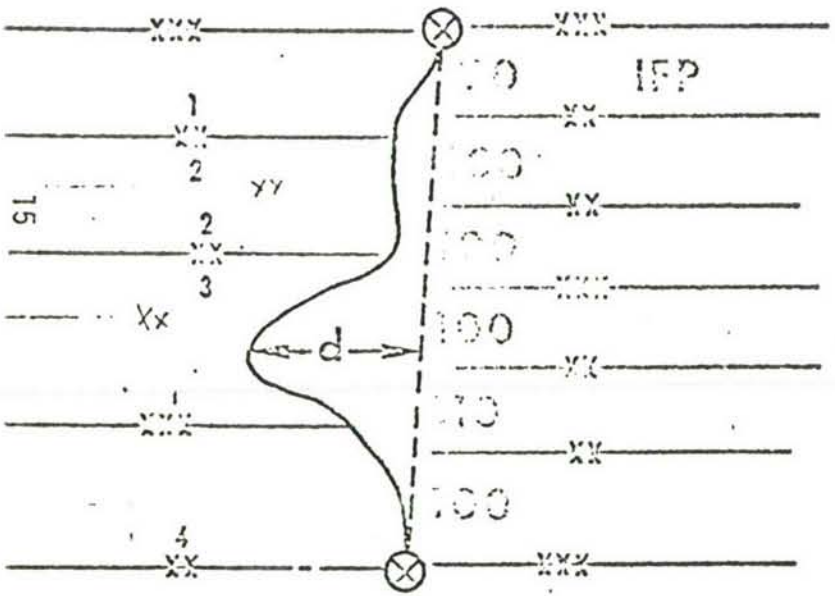


FIGURE 8

FIGURE 9

BLUE BOUNDARY CHANGE



RED STRENGTH OPPOSING A BLUE DIVISION OR CORPS IS MEASURED AS A FUNCTION OF d AND IFP

BLUE CORPS AND DIVISION BOUNDARIES ARE THEN SHIFTED SO THAT BLUE IFP IS PRO-RATED AGAINST THE RED d × IFP FUNCTION

up to corps level boundaries. Other flank protection devices include the drop-off of forces for flank protection and a maximum limit of exposed flank. There are different styles and types of output the user may select depending on the detail of reporting he desires. The CEM is a very large model both in terms of core storage and machine time required for even short war runs. The model requires a third-generation computer that can provide 100,000 words of core memory and 15 million words of disc memory. It is programed at present on our UNIVAC 1108 computer. Typically, two to three minutes of dedicated computer time is required to represent one combat day. If a 90-day war was fought, with 14 BLUE divisions against 35 RED divisions, it would take about five hours of computer time and one run would cost about $2,800 at week-end computer rates. Input requirements are formidable as might be expected. For a typical run some 15,000 individually determined items of input must be provided. Experiment shows that the initial preparation for a run involving a considerable change in terrain, deployment schedules and opposing forces can take an experienced staff some 8 to 12 weeks.

The CEM is used extensively here at the Concepts Analysis Agency for the continuing tasks of mid-range force planning. It is the principal tool used to evaluate conceptual forces under consideration for the mid-range (10 to 15 year) time period. This experience has revealed many opportunities for development and improvement that are being actively pursued. However, we consider the burden in computer demand, complexity of inputs, and running time to be at about the maximum tolerable. Accordingly, we seek a compensating simplification whenever we assay an additional capability. We anticipate a heavy demand to sensitize the CEM to elements of force structure the value of which (in terms of mission accomplishment) it does not inately measure. For example, we expect a major effort to sensitize the CEM to the contribution of such force elements as tactical communication, intelligence gathering, and engineer activities. It is likely that we will meet such demands by the design of special-purpose versions of the model rather than by continuing to increase the overall size into an omnibus CEM. In order to better use CEM results an Agency-wide program is being developed to document and record each model run. This will serve to coordinate model useage and give a more detailed history for future CEM improvements.

THE NEXT GENERATION OF WAR GAMES: A CONCEPTS PAPER

Anthony H. Cordesman
Senior Research Analyst
ARPA-TTO
(202) 694-1821

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SUMMARY

- Theater level and combined arms war games and simulations now under development are making major advances in the state of the art.

- Nevertheless, even these new games suffer from critical limitations. These limitations are sufficiently grave to require a "next generation" approach to improving their capability and realism before they can adequately support decision making.

- The priorities for such improvements are outlined in Table One.

- The lack of adequate theater level and combined arms models also limits the value of high resolution modeling to defense decision-making. Such detailed games or simulations cannot put the insights they provide into an adequate combined arms or force context.

- Significant advances are also needed in the way the design or architecture war game models is structured, made explicit, and justified. In sufficient effort is being paid to the limitations and sensistivites of such games in modeling literature.

- Current methods for opening the "black box" of computer models needs improvement. More explicit justification is needed for the way computer technology is being applied to gaming models.

- New approaches are required to the way data bases, measures of effectiveness, operations research, and military history are applied to gaming simulation. It is not enough to improve existing measures and techniques.

- More attention is needed to designing future games to explicitly support force planning, R&D, procurement, and resource allocation analysis. One major limitation in existing models is that they are relatively insensitive to the capabilities of components of tactical land and air forces which consume more than half of the total defense expenditures on land and air units.

- Similar attention is needed to the interface between static and dynamic analysis, and to the design of war games based on actual force plans and force structures rather than idealised images of force capability.

- The management and organisation of war gaming activity needs improvement as much as the games themselves. Such improvements include more emphasis on expanding existing models rather than developing whole new models, proper analysis of the "life cycle" utilisation of new games, and reductions in the extent to which gaming has become an adversary activity.

I. INTRODUCTION

Major advances are now occuring in the development of war gaming and simulation techniques. These advances affect both high and low resolution models and the development of the measures of effectiveness upon which they are based. Nevertheless, major problems remain unsolved even in the games still under development. These problems are sufficiently serious so that it seems useful to consider what advances will be required in the next generation of war games even before the current generation is completed.

Emphasis is placed on advances in theater and combined arms gaming for several reasons:

--Major force planning, procurement, and research and development decisions increasingly must be justified in terms of their force on force benefit and force-wide trade-offs.

--Advanced technology generally looks beyond the boundaries of existing roles and missions and a single service. Its value must be examined in broad terms and a combined arms context.

--Resource pressures on manpower, force size, and force improvements emphasize the need for models which can examine new mixes of technology, force structure, and tactics.

--Such models can improve the net assessment process by examining present and future force capabilities in a broad context. They reduce the risk of suboptimizing on improving a given capability of limited overall importance.

--It is only by using such models that maneuver, C^3, protection, and support can be properly examined. The present high resolution models used in the U.S. bias analysis towards firepower systems in direct meeting engagements for both land and air systems.

--New policies towards the use of tactical nuclear weapons emphasize the need for combined arms models which can examine both conventional and nuclear combat, and patterns of escalation or conversion to tactical nuclear conflict.

II. PRIORITIES FOR THE NEXT GENERATION OF MODELS

Table One is an attempt to list the advances that might be required in a next generation approach to modeling. Priorities are assigned largely on the extent to which such advances are required to support major decisions in force planning, research and development, and net assessment.

TABLE ONE

TASKS IN CREATING THE "NEXT GENERATION" OF THEATER-LEVEL AND COMBINED ARMS WAR GAMES AND SIMULATIONS

PRIORITY	IMPROVEMENT
1.	BREAKTHROUGHS AND MANEUVER WARFARE Modeling of breakthroughs, dispersed combat and defense, porous battlefields, and maneuver-oriented combat. Stress should be placed on the capability of "experimental forces" using advanced technology to attack and defend in intermingled and long range (> 5 KM) maneuver combat. Models should be explicitly capable of modeling flanking combat, "expanding torrent" attacks, envelopments, holding attacks, etc.
2.	AIR AND SAM "SYSTEM" CAPABILITIES Modeling of air and SAM capabilities in terms of actual deployment effects, AC&W/C^3/GCI/Netting capabilities, avionics capabilities, and associated weapons capabilities. Emphasis should be on force-on-force interaction rather than one-on-one or few-on-few encounters.
3.	RESERVE AND REINFORCEMENT DEPLOYMENTS Movement and deployment of reserve and reinforcement forces should be modeled explicitly. Such land and air units should be vulnerable during reinforcement movement and subject to realistic mission and national assignment constraints.
4.	RELOCATION AND CONCENTRATION Relocation and concentration of NATO ground forces from their EDP/GDP positions should be modeled. A "surprise attack" option against NATO forces in peacetime and movement postures should be provided. Warsaw Pact ability to exploit penetrations or concentrations of force should be modeled from possible initial peacetime or wartime positions in the GDR/Czech/Poland/Hungary.

TABLE ONE (continued)

PRIORITY	IMPROVEMENT
5.	THEATER AND CORPS LEVEL NON-MANEUVER FORCES Model the role and vulnerability of theater, Corps, and divisional non-combat or maneuver elements, and of major fixed facilities. This should explicitly allow the value of long range attack targeting and guidance technology to be modeled.
6.	FORCE IMPROVEMENTS Modeling various levels of force improvement in both sides by type. Examples of this would range from a better NATO tank without a similar improvement in Pact tanks to an ECM-proof/non-emitting Warsaw Pact SAM. In short, the model should be useful at looking at different force-on-force R&D strategies by mission or systems capability. It should allow rapid changes in the assumed systems capability on both sides.
7.	ADVANCED TECHNOLOGY Modeling of new advanced technology systems such as emitter locators, RPV's, PGM's, improved SAM's, hostile weapons locators, anti-tank/air defense weapons, etc. in a theater context.
8.	SYSTEM INTERFACES Modeling the "system" interfaces and capabilities of this technology, and its vulnerability, rather than idealizing its capability at the FEBA. For example, radar netting or emitter locator systems should look at the full range of targets in the GSFG--not simply at forward maneuver forces--and these systems should be subject to GSFG attack.
9.	ELECTRONIC WAR Model the "electronic war" for all key systems; specifically, model routines allowing different ECM/ECCM, emitter locator/kill, C^3, target acquisition, etc. systems to be modeled and analyzed.
10.	DIRECT /INDIRECT FIRE EFFECTIVENESS Provide an improved direct and indirect fire effect model to look at suppressive fire, CAS, and arty area fire, and AA-sortie degradation fire effects.

PRIORITY	IMPROVEMENT
11.	TRAINING AND READINESS Provide a capability to model cumulative (overall effectiveness) differences in training and readiness.
12.	CASUALTY AND DEFEAT CRITERIA Provide improved casualty and defeat criteria models sensitive to shock effects, stochastic losses of Commanders and key MOS, random losses of key C^3 links, etc. In short, measure the effectiveness of killing more than total personnel, aircraft/SAM's, major land weapons, maneuver elements, or LOC tons/day.
13.	TNW OPTION Provide a TNW capability option.
14.	SUPPLY/WAR RESERVE CONSUMPTION Adapt supply and war reserve consumption models to differences in NATO/Pact organization and capabilities. Improve modeling of use of advanced technology munitions.

This list may cumulatively be beyond the capabilities of any early new model, or group of models. Accordingly, some advances may be possible in the short term using existing or developmental models, others may be achievable only by developing a family or higherarchy of models, and still others may require long term development efforts and entire new models.

It must be emphasized, however, that the absence of any given advance is serious limitation on the value of modeling in supporting defense decision making.

A. The Impact of Current Design Limitations on Planning

The usual excuse for the failure of models to consider a critical aspect of the real world is that they provide useful insights rather than answers. This excuse is valid only to a degree. The fact that the models provide "insights" only in special or selected categories tends to bias decision makers to consider only what the model considers. Similarly, such insights must suffer from the fact that they cannot be based on the interaction between what the model does examine and what it does not examine. The insights are, therefore, always of uncertain value, blind in certain critical areas, and drawn by staffs which can become conditioned to consider only those factors which their model considers.

B. Effect on Other Detailed or High Resolution Models

Such problems limit the value of detailed high resolution models as well as that of low resolution combined arms or theater level models. The results of high resolution models cannot be placed in a combined arms or broad context. Their conclusions may do little more than exaggerate the value of the particular factors to which the high resolution model is sensitive since there are no broad low resolution models which act as proper analytic controls. In fact, much of the high resolution modeling within DoD may have reached the point where this lack of theater-wide or combined arms analytic control makes their results distort defense decision as much as aid it.

The modeling of improvements in anti-tank weaponery and of improvements in air weaponery and avionics, may provide examples of such cases. The inability to model maneuver effectively in virtually all tank/anti-tank models tends to bias the model towards improvements in killing capability rather than mobility. Similarly, the emphasis on high resolution models using small unit combat makes it almost impossible to properly look at trade-offs between force numbers and force quality.

Similar problems occur because of the fact that it is not clear that optimizing air systems using the results of small encounter models can provide a valid picture of overall operational priorities or force on force needs. Such air combat models also tend to over-emphasize improvements, technical performance capabilities, or have to be based on largely judgmental rationales for the trade-off point at which further improvements cease to be productive. Some models examining avionics needs are exceptionally hard to relate to overall force requirements because of their inability to properly consider system-wide electronic warfare and AC&W capabilities.

Accordingly, the priorities shown in Table One are not simply priorities for low resolution models. They affect all gaming and simulation that attempts to do more than explore the value of a limited range of technical improvements or to explore comparative performance value in isolation from the unmodeled factors that determined overall value in combat.

III. THE FOG OF MODELS AND THE FOG OF WAR

These issues are complex and difficult to summarize or document for a given model. This very complexity, however, leads to another requirement for the "next generation" of models. Modeling literature tends to lead the reader to conclude that few modelers subject themselves to the same analytic controls as other analysts who contribute to the process of defense decision making. While there are major exceptions, most descriptions of models are conspicuously silent about two key aspects of the models involved:

--The major limitations in the models involved.

--The probable uncertainty in the model results, and the reasons for going into a given degree of resolution in modeling.

A. Major Limitations in Models

Table Two is an attempt to indicate how modelers should open the "black boxes" their literature often creates around the major subroutines within their models. It sets a minimum list of data which should be included even in summary briefings on what high and low resolution models do. Any attempt to propose specific techniques to make the advances necessary for the next generation of models explicitly must provide such data.

TABLE TWO

DESCRIBING WAR GAME LOGIC BLOCS

- o Purpose
- o Sensitivities
- o Major Assumptions
- o Effectiveness Factors
- o Major Limitations
- o Comparisons w/ Other Models
- o Examples
- o Explicit outputs of what given weapon does
- o Relation to historical data fact
- o Uncertainties
- o Output format and Specific Outputs

B. Explicit Rationales for Levels of Resolution

At the same time, new models should explicitly deal with the problem of why a model goes into a given amount of detail in a given area, with the expected reliability or value of the result, and above all with the rationale for the sub-optimization on the different levels of logic and resolution contained within a model.

Much of the current literature on modeling leads the reader to assume that models "grew like Topsy" out of various past studies, and that little effort was made to analyze the overall requirements and analytic rationale the model should have. Some major models, in fact, go into incompatible levels of detail in ways which seriously limit their value. For example, a model may simulate the tank dual in exact detail,

but ignore indirect fire, the only sketchily portray location and targetability of anti-tank forces, and input tactical air only as an addition to force-wide tank killing potential. Air models may simulate air-to-air combat in detail, but use a roughly derived SAM attrition factor, and ignore air base deployment problems and AC&W capabilities. These incompatibilities rarely are specifically analyzed or justified.

Accordingly, the next generation of models must explicitly state the rationale for sub-optimization within the model, provide the necessary mathematical description and supporting figures, and explicitly describe the outputs in terms of the impact of given sub-routines or levels of resolution.

III. THE USE AND ABUSE OF COMPUTERS

Many computerized models raise serious questions as to why they were computerized in the first place. Some simple aspects of decision-making seem to take an inordinate amount of computer time to do the obvious, while others create very complex substitutes for human judgment with far less credible results. In general, there seems to be little explicit rationale in modeling literature for the way computers are used in given cases, or for the chosen man-computer interface. Instead, running time tends to be touted as an advantage per se, regardless of overall efficiency of the model or the trade-offs necessary to achieve that running time.

A. Explicit Justification of the Use of Computers

It is axiomatic that the modeling of cost-effectiveness is as subject to cost-effectiveness analysis as any other aspect of defense planning. Similarly, it is axiomatic that computers do not reduce personal judgment in modeling or the impact of personal value judgments on the result. All computers can do is hide, institutionalize, or compound such value judgments.

Accordingly, the next generation of models should be based also on an explicit justification of:

--The trade-offs selected to achieve a given level of computerization.

--The cost-effectiveness of the selected use of computers.

--The way in which judgments are modeled and their impact on the result.

--The cost-effectiveness of the level resolution and man-computer interface selected.

B. Opening the Black Box

The problem of computer output formats and process description formats needs similar explicit analysis. Most major models now under development should produce major strides forward in improving the depth of their output data, its clarity to the non-programmer, and the amount of description of just what the model has done in running its various black boxes.

These advances, however, do not seem to be based on an explicit study of what is required. Instead, they seem to represent aids to the game designer, uses of available computer routines, random interests of the game design staff, etc. Accordingly, they run the risk of producing a half open black box which may be worse than one that is conspicuously sealed shut. In the latter case, the user knows he doesn't understand what he is using; in the former he may have the illusion he does.

The next generation of models should do more than simply open their routines through detailed reporting and options for interactive gamer decision-making. They should be based on a detailed analysis of how open the black box should be, of the types of formats and outputs users need, and of the controls needed to ensure that outputs do not disguise unintended interactions or modeling processes.

IV. DATA BASES AND EFFECTIVENESS MEASURES

During the last decade, both modelers and intelligence experts have made major advances in their measures of effectiveness (MOE) and the force data on which modeling efforts must be based. There are, however, conspicuous gaps in the kinds of input data available and in the quality of current measures of effectiveness. Further, insufficient analytic thought seems to have been given to just what kinds of data and effectiveness measures are really required for theater-level and combined arms modeling. And, there seems to be a conspicuous absence of analytic justification for given types of integration between models, force data, and MOE, even on a basic statistical level.

Modelers often seem to accept data or measures of effectiveness without examining them in detail or insisting on statistical controls. They also fail to establish deliberate or explicit interactions between all of the inputs that affect the model. For example, attrition routines may be used in given areas with no interaction or controls from other parts of the model. The user is faced then with trying to calibrate the model by trying to change or force given inputs until the results seem logical, but can only partially trace the interaction that does occur or why it occurs.

It is impossible to combine given data and given measures of effectiveness into a model without setting up new patterns of interaction whether or not this is explicitly reported. Any two or more measures of effectiveness combine to form new measures of effectiveness whose overall impact may be far from clear. A case in point is the use of both firepower scores and force ratio advance data. These interact in current models in ways which the gamer can only partially understand. They create a new measure which can be described looselv in ways such as "weapons numbers times lethality equals force ratios relative to movement over time" but there is little data available to anyone how many meters twelve 155mm howitzers advance the FEBA in hours which is one explicit result of this new "measure of effectiveness."

There is also the problem of "feedback." A given routine using input data or MOE may provide no information to other routines or inputs in the model's mathematics. It may, itself, be blind to "feedback" from inputs to other routines. The result is a breakdown in the realism of combined arms planning which hopefully does not occur in the real world.

In short, it is conventional wisdom that improvements are required in input data and measures of effectiveness, but this begs the question of what improvements, with what priority, and why. The question is what kinds of new data and measures of effectiveness are required, and how their interaction should be analyzed and justified in creating new models.

V. OPERATIONAL TESTING AND HISTORICAL RESEARCH

It is similarly conventional wisdom that more use should be made of operational testing and historical research in providing measures of effectiveness, and in structuring models to adequately simulate the process of combat. The impact of human factors, tactical decisions in command, "efficiency" of combat are classic rationales of the need for more historical research and field testing. So is the failure of many predictive, or expected value, high resolution models to produce results which are supported by later field tests of the systems simulated or the systems behavior in combat.

The issue for the next generation of models is not, therefore, whether there is a need for more testing and historical research. It is rather what priorities exist for what research. This can only be established once proposals exist for next generation models, but

it is important that it be established in detail, and that new models should not pick up such research on a "catch as can" basis, or theorize expected values when empirical evidence can be derived.

VI. THE BROADER CONTEXT OF IMPROVED MODELING CAPABILITIES

War games and simulations rarely are only to explore the results of combat between two forces. They are instead used to support broader studies of issues which involve related political, budgetary, and R&D issues considerations. These overall study requirements are outlined in Table Three.

TABLE THREE

OVERALL REQUIREMENTS FOR IMPROVED STUDIES USING ADVANCED MODELING TECHNOLOGY

o Wargaming and Simulation

--Establish value of given technology in "force-on-force" comparison.
--Measure impact of technology on outcome of conflict in different scenarios.
--Establish force improvement priorities.
--Analyze counter-measures, counter-forces, and counter-tactics.
--Establish illustrative force requirements.
--Demonstrate tactical value.
--Put in NET Assessment context.

o Cost-Effectiveness Analysis

--Show PPBS feasibility.
--Determine approximate force cost.
--Establish total systems requirements.
--Analyze trade-off value.
--Relate to Issue Papers, Selected Analyses, DPPG, JRDOD, etc.

o R&D Strategy

--Trade-offs in time, cost, and capability.
--Phasing in terms of deployment.
--Phasing in terms of existing and future user systems.
--Phasing in terms of threat capabilities.
--Trade-offs with sunk costs, existing systems, and competing systems.

A. Resource Analysis and Research and Development

Existing theater level models are not designed specifically to support this broader context of decision making. They are oriented rather specifically towards the issue of "who wins what" when given input variables are changed. It would be desirable, however, if routines could be added to the next generation of modelings which allowed the user to examine some of these other study tasks more directly.

An example of such a routine would be the capability to explicitly consider force improvement cost as a measure of effectiveness, and to simplify the problems involved in trying to determine the most effective force that can be generated within a given level of investment or vice versa.

A more complex routine would be one that could compare different force mixes and life cycles over time to help determine R&D priorities and development strategies. It would be particularly useful, for example, to have a routine that could estimate the value of a given technology not simply at one point in time, but as a curve relative to other projected force changes and options open to the threat.

B. Impact on Studies

More thought is needed to these problems, and particularly if DoD is to make suitable long term improvements in the way it conducts and manages defense studies.

It seems fair to state that there is a wide dissatisfaction with the current state of "studies" in DoD. There are a great many reasons for this, but one reason that may receive insufficient attention is the fact that the current state of modeling fails to provide convincing answers to those questions which are of most direct interest to higher level decision makers.

They do not support decision making that fully considers combined arms problems, new force requirements, or all of the aspects of military effectiveness that are critical to force capabilities. They are structured so that the decision maker (and all other users) find it almost impossible to compare them, their results, and their validity. And, they suboptimize in conflicting and confusing ways, and leave the reader to try to integrate the insights provided with what the model fails to cover.

Accordingly, the search for a next generation of models should, to some extent, be seen as a factor in correcting the overall problems that limit the value of studies of defense planning. Without some such advances there may be a growing tendency to down play such "studies" and rely on personal experience, and staff judgments. Given the problems discussed earlier, it is difficult to criticize decision makers for doing this: the conclusions may be just as valid and they are certain to be more timely and cheap.

VII THE PROBLEM OF FORCES AND RESOURCES

These requirements for the use of war games in studies affecting broad resource and budgetary decisions also raise questions about the extent to which theater or combined arms war games should be sensitive to all of the major factors affecting force size and force cost. Support forces and rear area forces dominate both the size and cost of both land and air forces. Even developmental theater level games, however, are sensitive largely to resources spent on those units which possess firepower systems, and on combat air squadrons.

This may reflect a proper compromise between complexity and capability, but it is not an explicit or analyzed one. Little thought seems to be given to why given capabilities or forces are modeled and why others are not, or to the relationship between what is modeled and the need to allocate resources or overall force strength. There is also a tendency to confuse the modeling of "non-combat" forces with providing supply and LoC routines and/or replacement capability. This is not statiscally the function of most "non-combat" forces, and does not reflect the bulk of the force costs involved.

Accordingly, the next generation of war games should include a detailed analysis of the "PEMA paradox" of current efforts at simulation. It should be based on clear criteria for relating what is modeled to what is spent, and there should be a clear rationale for why given models are not sensitive to major elements of force cost or resources.

VIII FORCE STRUCTURE DIFFERENCES AND STATIC AND DYNAMIC ANALYSIS

A related problem exists in most current and developmental models because although they largely deal with the European theater, they are not derrived from a detailed analysis of the force structures on both sides, or linked to the static analysis of current force plans and

and national capabilities. Instead, the models are designed to a given image of combat and force structure -- almost inevitably based on U.S. and Soviet forces and doctrine -- and this is projected across the theater regardless of differences in the capabilities of the allied forces on both sides, and their internal force structures, and the levels of capability and in the systems designed to link them together.

This can be highly unrealistic, and is not corrected simply by having an accurate data base or standard effectiveness factors. OSD studies have shown in detail that Allied forces differ sharply from U.S. land forces in tactical concepts, balance of arms and weapons density, and their supply doctrine. Similarly, each NATO air force has strikingly different detailed air tactics, levels of CAS capability, avoinics equipment, and munitions types and balance even though the same aircraft may have wide standardisation. Such differences sharply affect the ability to use sorties effectively because of differences in national AC&W and recce doctrine and equipment, and the passive and active protection of air bases.

The next generation of war games should, therefore, be based on a careful examination of static force analysis, and of theater-wide and combined arms differences in force structures. It may not be profitable to simulate all such differences or consider them in detail. But, the choices in designed advanced war games should be deliberate ones, and any rejection of the factors that drive NATO or other Allied force planning, and of the factors that drive static analysis; should be clearly described and justified.

IX MODEL ARCHITECTURE AND LIFE CYCLE DESIGN

The need for such advances to support defense planning raises the issue of what the overall architecture of what the life cycle of the next generation of models should be. It seems almost certain that if future such models are to properly influence decision making, their architecture and life cycle should meet three major goals:

-- Make as much use of existing models and efforts as possible. Concentrate on improvements, not repeating existing work.

-- Provide as broad a structure and flexible an architecture as possible. Allow for the addition of new routines, improvement of old routines, and modules provided by other designers.

-- Maximize the life cycle of given models through evolution and improvement. Avoid going on to the next model, with all its learning curves, when constant improvement of an existing model can achieve better results.

The rationale for these goals is obvious, as is the need for more stability in modeling efforts as a whole. Too much time is being wasted trying to design the "X" model to meet complaints about the last model, and this is producing a confusing and ever changing cycle of models with defects, and which are never brought to the level of capability or life cycle their architecture makes possible.

Even next generation approach does not have to begin with whole new models unless some very convincing rationale exists for such an effort. The only immediate such rationale that seems to exist for such a whole new approach is the structural emphasis most developmental models now place on war fighting or war winning in total combat as distinguished from modeling combat driven by politico-military issues, inter and intra-war deterrence, and the process of conflict termination. It is far from clear, however, that developmental models cannot be adapted to examining such questions, or what aspects of such issues should be examined in theater level/combined arms models.

Accordingly, the search for a next generation of models should, to some extent, be seen as a factor in correcting the overall problems that limit the value of studies of defense planning. Without some such advances, there may be a growing tendency to down play such "studies" and rely on personal experience, and staff judgments. Given the problems discussed earlier, it is difficult to criticize decision makers for doing this: the conclusions may be just as valid and they are certain to be more timely and cheap.

X IMPROVING THE USER OF MODELS AND SIMULATIONS

A final task that needs significant effort is to better organize the ways in which models and simulations are used within DoD. Some of the major problems involved are listed in Table Four.

TABLE FOUR

MAJOR PROBLEMS

- o Poor understanding of model capabilities and limitations at the level of "decision maker."
- o How can model outputs best be processed and communicated to decision makers?
- o How can better problem and task statements be generated?
- o How much detail do given major types of decisions require; how much can be utilized?
- o How can high and low resolution models best be integrated or interfaced within DoD.
- o Theater level analysis is only economic as part of on-going activity, and possibly common effort. How can the cost of modeling be reduced or better distributed within all user agencies? How can more common efforts be set up.
- o How can a common data base, dealing with future capabilities on both sides, be set up?
- o What new field testing and measures of effectiveness analysis should be started?
- o What new intelligence and input data reporting is required?
- o Models must not only be valid, but convincing and accepted. How can DoD-wide review and standardization be improved?
- o How can limiting factors from bureaucratic sensitivities, special interests, biases, etc. be reduced?
- o Software problems: clerical processing and operating burden. Who should do what for whom?
- o Contractor/service agent problem: which should do the actual work? What is the probability of success and efficiency?
- o Poor ARPA/WSEG/DDR&E/NTA/OJCS/DPA&E/Services interface.
- o Key trade-off: when is analysis so difficult and uncertain that do better to suboptimize on funding interesting and competitive technology?
- o Problem of "shopping lists"; does methodology drive artificially towards more sophistication and higher requirements.
- o Do decision makers want "Determinism" or "Parametric Uncertainty."
- o How can cost problems and resource limitations be modeled? Tied to theater or combined arms models?
- o How can "life cycle" of current, and planned, systems be considered?

A. The Problem of Adversary Relationships

Unfortunately, a great deal of modeling and simulation work is used in, and tailored to, the adversary support of given policies, technology, and budget issues. This tends to pressure the various components of DoD into developing their own modeling efforts, and this competition compounds the problems of making any given model adequate and the tendency of decision makers at the receiving end to be dubious about the value of the result in decision making.

There are, several reasons for reducing the extent of this competition which deserve consideration in creating a further generation of models:

-- Standardization on a family of models could cut significantly the cost of current modeling efforts, and provide the resources for more complex models to be run.

-- Such standardization could play a useful role in leading each component of DoD to look at broader issues. It would help ensure that planning occurred in a combined arms and force on force context.

-- A common effort could do much to reduce the paralysis of "static" versus "dynamic" analysis, and to allow both methods to be used more effectively.

-- Adversary analysis can be useful only to the extent it is open, explicit, and based on common tools and premises. Competing models, each looking at selected parts of the problem, do not provide competing insights, but a competing lack of them.

-- Much of the operational value of models depends on a close link between the staffs using the models, the staffs providing input data and MOE, and the tasking staff or decision maker. The present range of competing models precludes such a common link from being effective. It provides little incentive for either the reviewer or inputer to fully understand the complexity of the models involved.

B. The Value of an Inter-Agency Approach

Organizations such as SAGA, DPA&E, and WSEG are already making important improvements in the integration of the modeling

effort. It may be optimistic to hope that planners will readily give up their in-house tools for any type of common effort. Nevertheless, there seems to be more competition between models than seems useful even in supporting the parochial interests of their sponsors in influencing decision makers.

In fact, such competition may be as damaging to the reputation of studies in DoD as the limitations in the models themselves. No high echelon staff member or decision maker has the time or incentive to really understand the rapidly changing range of different tools being used, or to take the time to be sure that they are properly being used to meet his needs. He can, however, be sure that a competing view will always emerge from a different model, and that no given model (or studies that use it) will be accepted as "proving" anything.

Accordingly, it seems useful to consider whether the next generation of models should not be developed under some kind of inter-Agency and inter-Service effort, and whether some continuing review board of experts within DoD should not be tasked with overseeing how such models are being used and the problems that are emerging in their structure or application.

IMPROVING THEATER LEVEL WAR GAMES

PRESENTATION AIDS

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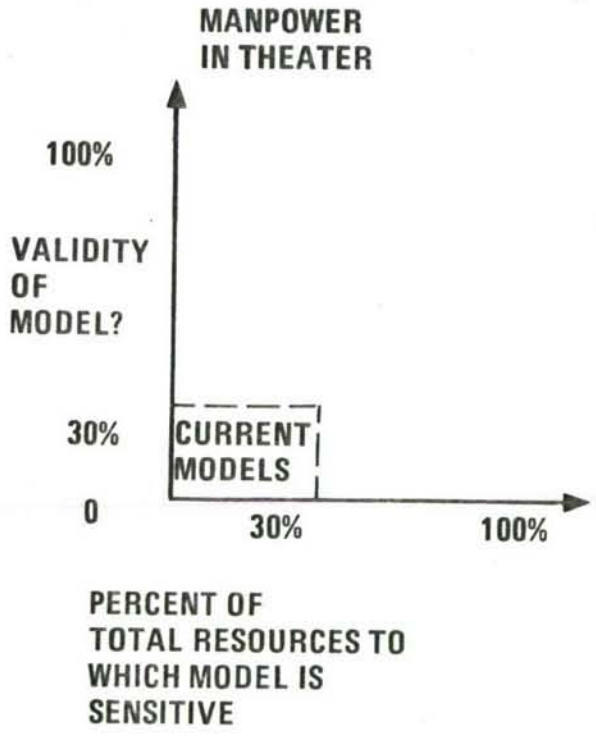
ANTHONY H. CORDESMAN
CHIEF, PRODUCT EVALUATION DIVISION
OASD(INTELLIGENCE)

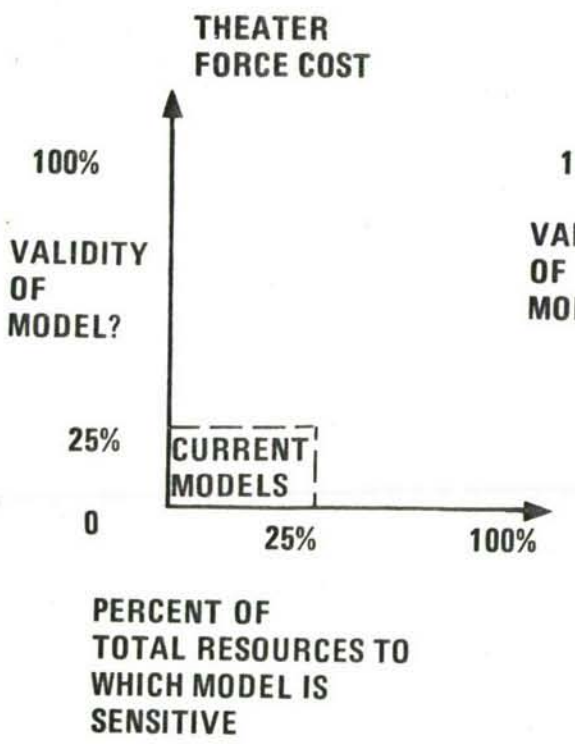
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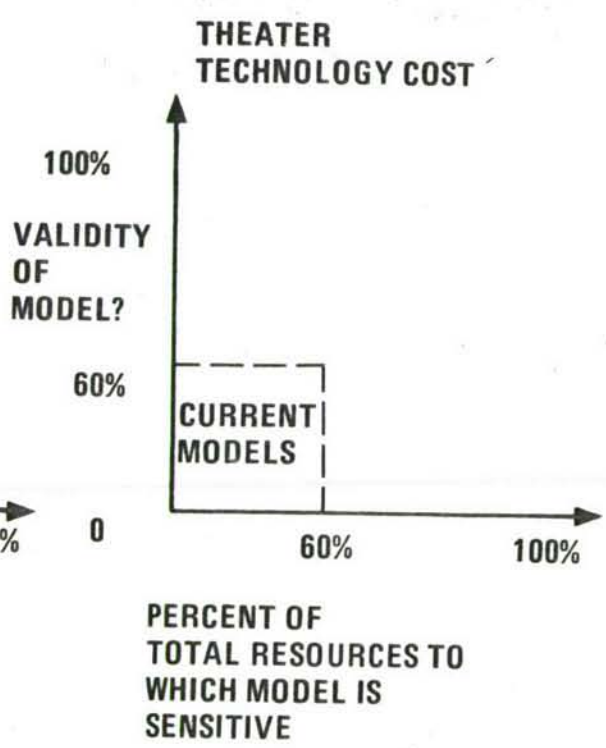
TYPICAL SHORTFALLS IN CURRENT AND DEVELOPMENTAL MODELS

- INABILITY TO MODEL ENTIRE PROCESS OF MANEUVER, ESPECIALLY BREAKTHROUGHS, ENVELOPMENTS, AND POROUS COMBAT
- INABILITY TO MODEL EFFECT OF AIR BASE, SAM, AND SSM DEPLOYMENTS AND RANGE CAPABILITIES. INSENSITIVITY TO REAL WORLD "FORCE ON FORCE" CAPABILITIES SUCH AS RECCE, AC&W, EW, ECM/ECCM, AND C^3
- FOCUS ON KILLING ORIENTED MEASURES OF EFFECTIVENESS RATHER THAN COMBINED ARMS PROCESSES
- INABILITY TO MODEL TNW AND CONVENTIONAL COMBAT SIMULTANEOUSLY, SEVERE LIMITATIONS IN REALISM OF TNW ROUTINES
- INSENSITIVITY TO "REAR AREA" STRUCTURE AND CAPABILITIES, SUPPORT FORCES, CASERNE AND DEPOT CAPABILITIES, ETC.

SENSITIVITY OF CURRENT THEATER LEVEL MODELS TO TOTAL COSTS & RESOURCES







IMPLICATIONS OF MODELING SHORTFALLS ON DECISION MAKING

- LIMIT VALIDITY OF FORCE PLANNING AND FORCE REQUIREMENTS STUDY
- INHIBIT ADEQUATE "FORCE-ON-FORCE" ANALYSIS
- MAKE IT DIFFICULT TO PLACE RESULTS OF HIGH RESOLUTION OR DETAILED MODELS IN FULL THEATER-WIDE OR COMBINED ARMS CONTEXT
- RESTRICT ABILITY TO EFFECTIVELY ANALYZE VALUE OF MANY ADVANCED R&D SYSTEMS OR ESTABLISH COMPARATIVE TECHNOLOGY CAPABILITIES WITH THREAT
- INHIBIT DEVELOPMENT OF NEW FORCE CONCEPTS, TACTICS, ROLES, AND MISSIONS
- LIMIT ABILITY TO EXAMINE POLITICO-MILITARY PROBLEMS SUCH AS MBFR
- HURT QUALITY OF "STUDIES" IN DOD. LEAD TO INDETERMINATE RESULTS, DEMANDS FOR FURTHER STUDIES, COMPETING CONCLUSIONS
- RESTRICT ABILITY TO ANALYZE RETURN ON R&D INVESTMENT AND FORCE IMPROVEMENTS

THE DATA BASE

- GIGO – "YOU ARE WHAT YOU EAT."
- SAGA/DPAE/DIA DATA BASE IS KEY STARTING POINT
- JOINT FORCE REQUIREMENTS STUDIES PROVIDE ADDITIONAL KEY DATA INPUTS
- NEW UNDERSTANDING OF COMBINED ARMS TACTICAL BEHAVIOR PROCESSES WILL CREATE DEMANDS FOR NEW TYPES OF DATA
- NEW TECHNOLOGY – PARTICULARLY THE SYNERGISTIC EFFECTS OF NEW SYSTEMS ALSO FORCES NEW DATA REQUIREMENTS
- MUST MOVE BEYOND "THE OLD GAME OF KILLING." NEED DATA ON THE ENTIRE FORCE STRUCTURE. CONSIDER READINESS, SUPPORT, MANEUVER, TACTICS
- FUTURE MODELS WILL REQUIRE NEW DATA AND INTELLIGENCE INPUTS

MILITARY EFFECTIVENESS INDICES (MEI)/ MEASURES OF EFFECTIVENESS (MOE)

- TRADITIONAL STATIC MEI/MOE APPROACH MAY NOW BE OUTDATED
- IF CANNOT MOVE BEYOND QUANTIFIED VALUE JUDGMENTS, THEN CALL THEM "QUANTIFIED VALUE JUDGMENTS"
- "ENGINEERING" MODELS USING MEASURES OF EFFECTIVENESS MAY BE NO SUBSTITUTE FOR DESCRIPTIONS OF COMBINED ARMS PROCESSES
- NOTHING WRONG IN USING IFP, WEI, KP, PH, ETC. IF REALIZE IS REALLY A JUDGMENT ABOUT THE VALUE OF A WEAPON IN THE COMBINED ARMS PROCESS RATHER THAN AN ACTUAL MOE
- REALITY TELLS US THAT NUMBERS AND THE QUALITY OF PERSONNEL DOMINATE THE OUTCOME OF WAR. MOES TELL US THAT FINE DIFFERENCES IN TECHNOLOGY DOMINATE COMPUTERIZED SANDBOXES
- THESES: MOST HIGH-LEVEL DECISION MAKERS HAVE BETTER INTUITIVE JUDGMENTS ABOUT SYSTEM EFFECTIVENESS THAN MOST TRADITIONAL STATIC MEI/MOE DESIGNERS

THE PROBLEM WITH MILITARY HISTORY AS AN INPUT TO MODELING

- IF THE PROCESS OF WAR CAN BE QUANTIFIED, THE U.S. HAS YET TO DO IT
- MOST DATA WHICH CAN BE QUANTIFIED IS "SOFT," AMBIGUOUS, OR SUBJECT TO CONTROVERSY
- MUCH OF THE MOST CRITICAL HISTORICAL DATA HAS NEVER BEEN QUANTIFIED
- CAN USE HISTORY ONLY TO GAIN INSIGHTS AS TO THE BOUNDS OF THE POSSIBLE
- THESIS: THOSE WHO FORGET THE PAST ARE CONDEMNED TO REPEAT IT
- COUNTER THESIS: THOSE WHO LIVE IN THE PAST WILL NEVER SURVIVE THE FUTURE

THE COMBINED ARMS PROCESS

- CANNOT BASE SIMULATIONS ON DUBIOUS DATA FROM DEAD WARS
- MUST SHIFT AWAY FROM ARTIFICIAL AGGREGATIONS OF "MEASURES OF EFFECTIVENESS"
- NEED TO DESCRIBE COMBINED ARMS AS A SET OF SYNERGISTIC PROCESSES:
  - BASED AS MUCH AS POSSIBLE ON FIELD TRIALS, TESTS, AND EXERCISES
  - USING MODERN WEAPONS SYSTEMS AND TECHNOLOGY
  - TIED TO THEATER-WIDE CONTEXT
- CANNOT LIMIT MODEL TO ROLES AND MISSIONS OF DEAD WARS; MUST CONSIDER NEW COMBINED ARMS MISSIONS ADVANCING TECHNOLOGY CREATES
- MUST ACCEPT THE MONTE CARLO NATURE OF FUTURE COMBINED ARMS ACTION

LESSONS FOR HIGH RESOLUTION MODELS

- MOST USE MEIs/MOEs AND EXPECTED VALUE MODELS. THIS MAY FALL FAR SHORT OF WHAT CAN NOW BE ACHIEVED BY COMBINING MODELING AND TESTING INTO DESCRIPTIONS OF COMBINED ARMS PROCESS
- CANNOT NOW PLACE RESULTS OF SUCH MODELS IN ADEQUATE COMBINED ARMS OR THEATER-WIDE CONTEXT
- WITHOUT SUCH ANALYTIC CONTROLS, HIGH RESOLUTION MODELS BIAS THE USER TO THINK IN TERMS OF THE LIMITED FACTORS TO WHICH THE MODEL CHOSEN IS SENSITIVE
- IN MANY CASES, SUCH MODELS REINFORCE CONTINUING SUBOPTIMIZATION ALONG PAST LINES OF TECHNOLOGICAL DEVELOPMENT OR FOR PAST ROLES AND MISSIONS
- THIS TENDS TO LEAD USERS TO "GOLD PLATE" EXISTING CAPABILITIES
- HIGHEST PAYOFFS MAY LIE IN NEW ROLES AND MISSIONS, NEW FORCE CONCEPTS
- HIGHEST MILITARY AND R&D RISKS MAY LIE IN WHAT SUCH HIGH RESOLUTION MODELS CANNOT CONSIDER

CURRENT GROUND COMBAT MODELING CAPABILITIES

SMALL UNIT ACTION

- EXCHANGE SIMULATION EFFECTIVE BUT LEAVE UNIT ISOLATED
  - ANALYTIC ABSTRACTIONS REASONABLE
    - CAN MODEL BETTER THAN OTHER AREAS

DIVISION/CORPS LEVEL

- SIMULATIONS CUMBERSOME
  - ANALYTICAL ABSTRACTIONS INADEQUATE
    - INTERACTIVE GAMES LIMITED VALUE

THEATER LEVEL

- TOTAL SIMULATIONS INCLUDING ALL EVENTS IMPRACTICAL
  - AGGREGATION REQUIRED
    - FPP UNSATISFACTORY

AIR BATTLE MODEL REQUIREMENTS

- "FORCE ON FORCE" STRUCTURE; NOT JUST AIRCRAFT VS. AIRCRAFT OR AIRCRAFT VS. GROUND SYSTEMS
- EXPLICITLY MODEL AIRBASE, AA/SAM, AC&W, AND REAR AIR FACILITY DEPLOYMENTS
- HANDLE FULL RANGE OF NATO/WARSAW PACT AIRCRAFT, SAM, AND AA WEAPONS
- MODEL CONVENTIONAL AND NUCLEAR MUNITIONS
- HANDLE SORTIE RATE DEGRADATION DUE TO BASE ATTACKS AND BATTLE DAMAGE
- MODEL EFFECTS OF AIR FORMATIONS AND TACTICS
- MODEL ROLES, MISSIONS, AND NATIONAL ASSIGNMENT CONSTRAINTS
- MODEL BASE DEFENSE, SWEEP, CAP, ESCORT
- CLOSE AIR SUPPORT AND GROUND ATTACK FROM FEBA THROUGH REAR AREAS
- DEFENSE SUPPRESSION/ATTACK
- ELECTRONIC WAR/EMITTER LOCATION AND TARGETING

AIR BATTLE MODEL REQUIREMENTS - (CONTINUED)

- RECONNAISSANCE, TARGET LOCATION AND IDENTIFICATION, DAMAGE ASSESSMENT/EFFECT
- AC&W/C^3 CAPABILITIES
- AIRLIFT
- REFUELING
- BASE REPAIR/DISPERSAL/EMERGENCY STRIP CAPABILITIES

MAJOR PROBLEMS IN IMPROVING TNW MODELS

- NON-TECHNICAL EFFECTS OF NUCLEAR WEAPONS
- LAND/AIR/SAM/SSM INTERFACE
- TNW/CONVENTIONAL INTERFACE
- MODELING OF FACILITIES, REAR AREAS, ACTUAL LOCATIONS
- INTEROPERABILITY, AND NATIONAL PLANNING CONSIDERATIONS
- C^3, RELEASE, TARGET ACQUISITION, EFFECTS ASSESSMENT, INTELLIGENCE REACTION TIME, ETC.
- IMPACT OF NEW TECHNOLOGY
- GAME TIME VS REAL TIME
- PLAYER, METAGAME, SELF OPTIMIZING OR ENFORCING OPTIONS IN MODELING RISK, DETERRENCE, ESCALATION CONTROL, AND CONFLICT TERMINATION

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FOG OF MODELS AND FOG OF WAR: KEY SILENCES IN MODELING LITERATURE

- THE MAJOR LIMITATIONS IN THE MODELS INVOLVED
- THE PROBABLE UNCERTAINTY IN THE MODELING RESULTS
- THE RATIONALE FOR GOING INTO A GIVEN DEGREE OF RESOLUTION IN MODELING
- WHAT FORCE CAPABILITIES THE MODEL IS NOT SENSITIVE TO

OPENING THE "BLACK BOX"

- HALF OPEN BOXES ARE WORSE THAN SEALED ONES. THEY GIVE THE ILLUSION OF UNDERSTANDING
- ONE KEY TASK IS TO OPENLY ADMIT HOW LITTLE WE KNOW ABOUT FUTURE WAR
- LIMITED GAMES PRODUCE LIMITED INSIGHTS. IF THE BLACK BOX CONCEALS WHAT THE GAME DOES NOT DO, IT BIASES THE USER TO BE EQUALLY INSENSITIVE TO REALITY
- SOME "MAXIMS" FOR THE NEXT GENERATION OF GAMES
  - THE GAME IS ONLY AS GOOD AS IT IS EASY TO UNDERSTAND
  - THE OPERATOR DOESN'T UNDERSTAND WHAT HE CANNOT MAKE THE USER UNDERSTAND
  - EXPLICITNESS IS MORE IMPORTANT THAN THE REALISM OF THE MODEL

DESCRIBING WAR GAME LOGIC BLOCS

- PURPOSE
- SENSITIVITIES
- MAJOR ASSUMPTIONS
- EFFECTIVENESS FACTORS
- MAJOR LIMITATIONS
- COMPARISONS WITH OTHER MODELS
- EXAMPLES
- EXPLICIT OUTPUTS OF WHAT A GIVEN WEAPON DOES
- RELATION TO HISTORICAL DATA FACT
- UNCERTAINTIES
- OUTPUT FORMAT AND SPECIFIC OUTPUTS

OVERALL REQUIREMENTS FOR IMPROVED STUDIES USING ADVANCED MODELING TECHNOLOGY

- WARGAMING AND SIMULATION
  - ESTABLISH VALUE OF GIVEN TECHNOLOGY IN "FORCE-ON-FORCE" COMPARISON
  - MEASURE IMPACT OF TECHNOLOGY ON OUTCOME OF CONFLICT IN DIFFERENT SCENARIOS
  - ESTABLISH FORCE IMPROVEMENT PRIORITIES
  - ANALYZE COUNTER-MEASURE COUNTER-FORCES, AND COUNTER-TACTICS
  - ESTABLISH ILLUSTRATIVE FORCE REQUIREMENTS
  - DEMONSTRATE TACTICAL VALUE
  - PUT IN NET ASSESSMENT CONTEXT
- COST-EFFECTIVENESS ANALYSIS
  - SHOW PPBS FEASIBILITY
  - DETERMINE APPROXIMATE FORCE COST
  - ESTABLISH TOTAL SYSTEMS REQUIREMENTS
  - ANALYZE TRADE-OFF VALUE
  - RELATE TO ISSUE PAPERS, SELECTED ANALYSES, DPPG, JRDOD, ETC.
- R&D STRATEGY
  - TRADE-OFFS IN TIME, COST, AND CAPABILITY
  - PHASING IN TERMS OF DEPLOYMENT
  - PHASING IN TERMS OF EXISTING AND FUTURE USER SYSTEMS
  - PHASING IN TERMS OF THREAT CAPABILITIES
  - TRADE-OFFS WITH SUNK COSTS, EXISTING SYSTEMS, AND COMPETING SYSTEMS

TASKS IN DEVELOPING ADVANCED THEATER-LEVEL AND COMBINED ARMS WAR GAMES AND METHODOLOGIES

PRIORITY	IMPROVEMENT
1	BREAKTHROUGHS AND MANEUVER WARFARE
2	AIR AND SAM "SYSTEM" CAPABILITIES AND DEPLOYMENTS
3	RESERVE AND REINFORCEMENT CAPABILITIES AND DEPLOYMENTS
4	RELOCATION AND FORCE CONCENTRATION CAPABILITIES
5	THEATER AND CORPS LEVEL NON-MANEUVER AND SUPPORT FORCES
6	FORCE IMPROVEMENT EFFECTS
7	ADVANCED TECHNOLOGY
8	SYSTEM INTERFACES
9	ELECTRONIC WAR
10	DIRECT/INDIRECT FIRE EFFECTIVENESS
11	TRAINING AND READINESS
12	CASUALTY AND DEFEAT CRITERIA
13	TNW OPTION*
14	SUPPLY/WAR RESERVE CONSUMPTION

*NOT PRIORITY FOR TNW ANALYSIS. BUT EFFECTIVE TNW MODEL DEPENDS ON ADVANCES IN PREVIOUS AREAS.

MAJOR ISSUES IN INTERAGENCY USE OF WAR GAMES AND SIMULATIONS

- HOW CAN HIGH AND LOW RESOLUTION MODELS BEST BE INTEGRATED OR INTERFACED WITHIN DOD?

- THEATER LEVEL ANALYSIS IS ONLY ECONOMIC AS PART OF ON-GOING ACTIVITY, AND POSSIBLY COMMON EFFORT. HOW CAN THE COST OF MODELING BE REDUCED OR BETTER DISTRIBUTED WITHIN ALL USER AGENCIES? HOW CAN MORE COMMON EFFORTS BE SET UP?

- HOW CAN COST PROBLEMS AND RESOURCE LIMITATIONS BE MODELED? TIED TO THEATER OR COMBINED ARMS MODELS?

- EFFECTIVE PLANNING AND COORDINATION OF THE LIFE CYCLE OF MODELS. COORDINATION OF DECISIONS ON "NEW DESIGN" VERSUS "MODIFICATION AND IMPROVEMENT"

ISSUES IN IMPROVING THE USE AND "USER" OF ADVANCED COMBINED ARMS MODELS

- HOW CAN "DECISION MAKER'S" UNDERSTANDING OF MODEL CAPABILITIES AND LIMITATIONS BE IMPROVED?
- HOW CAN MODEL OUTPUTS BEST BE PROCESSED AND COMMUNICATED TO DECISION MAKERS?
- HOW CAN BETTER PROBLEM AND TASK STATEMENTS BE GENERATED?
- HOW MUCH DETAIL DO GIVEN MAJOR TYPES OF DECISIONS REQUIRE; HOW MUCH CAN BE UTILIZED?
- KEY TRADE-OFF: WHEN IS ANALYSIS SO DIFFICULT AND UNCERTAIN THAT DO BETTER TO SUBOPTIMIZE ON FUNDING INTERESTING AND COMPETITIVE TECHNOLOGY?
- PROBLEM OF "SHOPPING LISTS"; DOES METHODOLOGY DRIVE ARTIFICIALLY TOWARDS MORE SOPHISTICATION AND HIGHER REQUIREMENTS?
- DO DECISION MAKERS WANT "DETERMINISM" OR "PARAMETRIC UNCERTAINTY"?

ISSUES IN IMPROVING THE ORGANIZATIONAL INFRASTRUCTURE FOR ADVANCED COMBINED ARMS MODELS

- HOW CAN A COMMON DATA BASE, DEALING WITH FUTURE CAPABILITIES ON BOTH SIDES, BE SET UP?
- WHAT NEW FIELD TESTING AND MEASURES OF EFFECTIVENESS ANALYSIS SHOULD BE STARTED?
- WHAT NEW INTELLIGENCE AND INPUT DATA REPORTING IS REQUIRED?
- MODELS MUST NOT ONLY BE VALID, BUT CONVINCING AND ACCEPTED. HOW CAN DOD-WIDE REVIEW AND STANDARDIZATION BE IMPROVED?
- HOW CAN LIMITING FACTORS FROM BUREAUCRATIC SENSITIVITIES, SPECIAL INTERESTS, BIASES, ETC. BE REDUCED?
- SOFTWARE PROBLEMS: CLERICAL PROCESSING AND OPERATING BURDEN, WHO SHOULD DO WHAT FOR WHOM?
- CONTRACTOR/SERVICE AGENT PROBLEM: WHICH SHOULD DO THE ACTUAL WORK? WHAT IS THE PROBABILITY OF SUCCESS AND EFFICIENCY?
- WHAT NEW COMPUTER FACILITIES AND CAPABILITIES ARE REQUIRED?

30 July 1974

STANDARDIZING SIMULATION AND WAR GAME ATTACK GENERATORS AND ASSESSORS

Anthony H. Cordesman
ARPA/TTO
202-694-1821

TABLE ONE

TASKS IN STANDARDIZING ATTACK GENERATORS AND ASSESSORS

- EXTREMELY COMPLEX PROBLEM
- MUST STANDARDIZE:
  - -- INPUTS TO ATTACK GENERATOR
  - -- OUTPUTS TO ATTACK ASSESSOR
  - -- PROCESSES LINKING GENERATOR TO ASSESSOR
- CANNOT LET FACT THINGS HAVE SAME NAME IN GAMES IMPLY STANDARDIZATION. MUST MEAN THE SAME THING.
- SCALE OF TASK ILLUSTRATED IN NEXT THREE TABLES.

TABLE TWO

KEY INPUTS IN STANDARDIZING ATTACK GENERATORS

- FORCE COMPOSITION AND STRENGTH DATA
- BUILD-UP AND REINFORCEMENT CAPABILITIES
- EXTENT TO WHICH C^3, INTELLIGENCE, EW, AC&W ARE MODELED
- NONGAMED OR SIMULATED MEASURES OF EFFECTIVENESS
  - -- MOVEMENT RATES
  - -- SORTIE EFFECTIVENESS
  - -- ENCOUNTER OUTCOMES AND RATIOS
  - -- IFP/P_K/P_H/WEI, ETC.
- SUPPLIES, STOCKS, AND WAR RESERVES
- LOCATION DATA
- FORCE DENSITY AND ARRAY DATA
- EXTENT TO WHICH TARGET ACQUISITION, FORCE ALLOCATION, AND DAMAGE ASSESSMENT ARE MODELED
- PERCENTAGE AND TYPES OF FORCES MODELED.
- DEFINITIONS AND TYPES OF ROLES, MISSIONS, AND FORCE CAPABILITIES MODELED

TABLE THREE

KEY FACTORS IN STANDARDIZING THE "GAME PROCESS" WHICH LINKS ATTACK GENERATORS AND ASSESSORS

- SENSITIVITY TO GIVEN TYPES OF INPUT DATA.
- PROCESS OF ASSESSING AND REACTING TO DAMAGE AND CASUALTY EFFECTS.
- WAY IN WHICH EFFECTIVENESS FACTORS SIMULATED OR MODELED IN GAME ARE STRUCTURED.
- TIME RATE: GAME TIME OR TIMES.
- WAY IN WHICH GIVEN PARTS OF FORCE ARE PLACED AT RISK.
- EXTENT TO WHICH FORCE ROLES, MISSIONS, AND CAPABILITIES ARE MODELED.
- METHOD OF SIMULATING OR MODELING FORCE LOCATIONS AND MOVEMENT.
- RATE OF GENERATOR/ASSESSOR INTERACTION WITHIN ALL ELEMENTS OF GAME AND MODEL.

TABLE FOUR

KEY OUTPUTS IN STANDARDIZING ATTACK ASSESSORS

- TYPE OF CASUALTY AND OTHER EFFECTS GIVEN AS OUTPUTS.
- CASUALTY EFFECT OF GIVEN WEAPONS, MUNITIONS, EXCHANGES, AND ENCOUNTERS.
- DEFEAT CRITERIA.
- DAMAGE AND KILL CRITERIA.
- DELAYED CASUALTY EFFECT
- PERCENTAGE AND TYPE OF FORCE AND FACILITIES AT RISK.
- IMPACT ON CAPABILITY OF SURVIVING FORCE AND FORCE AVAILABILITY.
- FORCE MOVEMENT AND MANEUVER EFFECT.
- SHOCK, SUPPRESSION, AND OTHER "NONDIRECT" CASUALTY EFFECTS.
- REPAIRABILITY AND RECOVERY CAPABILITY OF WEAPONS, SYSTEMS, AND FORCES.

TABLE FIVE

IMPLICATIONS FOR ANALYSIS

- MODELS MUST BE DESIGNED FROM START TO ACHIEVE THIS LEVEL OF STANDARDIZATION.
- INVOLVES INPUTS, PROCESSES, AND OUTPUTS WHERE STATE OF THE ART IS CONSTANTLY CHANGING AND IMPROVING.
- WOULD FORCE ALL MODELS TO HAVE SAME LEVEL AND STRUCTURE OF ABSTRACTION.
- IMPOSES MASSIVE COMPUTATIONAL BURDEN.
- MUCH OF STANDARDIZATION WILL HAVE LITTLE VALUE IN MOST CASES.

TABLE SIX

CONCLUSIONS

- COMMONALITY AND COMPATABILITY ARE USEFUL GOALS, BUT:
  - -- TRUE STANDARDIZATION IS NOT WORTH THE COST AND IS PROBABLY BEYOND STATE OF THE ART.
  - -- CANNOT "FREEZE" ANALYSIS TO MEET GOAL OF STANDARDIZATION IN ANY CASE.
  - -- MODELS USE DIFFERENT INPUTS, PROCESSES AND OUTPUTS BECAUSE DIFFERENT PROBLEMS REQUIRE DIFFERENT LEVELS OF ABSTRACTION.
- IS, HOWEVER, OF KEY IMPORTANCE TO COMPARE GENERATORS AND ASSESSORS. STRIVE FOR SHIFT TOWARDS COMMONALITY. MUST GIVE SAME IMPROVEMENT PRIORITY AS PROCESS OF MODELING AND SIMULATION.

THEATER FORCE EVALUATION SYSTEM

by

J. A. Bruner
P. E. Louer
General Research Corporation
Operations Analysis Division
Westgate Research Park, McLean, Virginia 22101

BACKGROUND

For many years the required size and mix of combat arms in the US Army were based largely on professional judgment and experience. Unfortunately, this basis has become less and less appropriate in view of the changing threat to NATO forces. For example, the firepower distribution among the combat arms within an armor-heavy force in World War II was about 20 percent in armor, 45 percent in infantry, and 35 percent in artillery. Compare this to a Soviet force recently facing the US 7th Army, in which the firepower distribution was 70 percent in armor, 10 percent in infantry, and 20 percent in artillery. A US force balanced on the basis of World War II experience would clearly be seriously out of balance against this Soviet force.

The dependence of force planning on experience and judgment resulted in part from the lack of theater combat models that properly represented the interactions among the combat arms. Aware of this lack, the General Research Corporation (at that time the Research Analysis Corporation) undertook the development of a new theater combat model, in which the outcome of a theater battle was to be properly sensitive to the mixes of combat units on both sides, and was to reflect command decisions concerning missions and allocations of available resources.

This model, now called ATHENA, progressed through its development in several cyclical stages in which (a) applications were made to evaluate different theater force combinations, and then (b) model modifications were made to correct observed weaknesses. These cycles have taken place as part of a US Army study which has had as its objective to "develop a conceptual design for the Army in the field which will provide the best Army capabilities attainable within projected levels of resources available during the mid-range period." In support of this study, ATHENA has been employed to evaluate at least 25 widely varying theater force alternatives. These include some forces emphasizing armor, others heavy in mechanized infantry, some heavy in attack helicopters, and even some in which a great deal of dependence was placed on barrier construction by combat engineers. Including minor variations to these forces and model

sensitivity analyses, several hundred ATHENA evaluation runs have been made, with some of these simulated wars continuing for as long as six months.

In the following pages, the principal features of ATHENA are highlighted, the structure of the model is described, and, finally, the measures of force performance produced by ATHENA are discussed along with possible applications of the model.

PRINCIPAL FEATURES

ATHENA is a fully-automated, deterministic computer simulation of theater-level, non-nuclear warfare with a continuous FEBA. Once the inputs have been developed and the computer "Start" button pushed, the simulation proceeds without user intervention.

One of its most important features is the extensive set of decision routines. Periodically during the war a commander's estimate of the situation is made for each unit on both sides, at every echelon from division up to theater. These estimates of the situation are then used as the basis for decisions concerning the assignment of missions and unit boundaries, allocation of fire support, commitment and reconstitution of reserves, assignment of reinforcement units, and allocation of logistic resupply. This feature permits each side to respond tactically to earlier activity of the enemy and assures that forces are employed in accordance with appropriate doctrine.

Combat is resolved in ATHENA to brigade-level engagements. The outcome of each engagement is sensitive to the mix of weapons within the combat forces (and Tac Air) on both sides. This feature, together with the spectrum of engagement types generated by the model, makes the outcome of a campaign sensitive to the structure of the theater combat forces.

Campaign tempo and outcome are also quite sensitive to resource expenditure on both sides—casualties, losses of major weapons, and consumption of supplies by class—and to the associated resupply and replacement rates.

Combat across an entire theater can be portrayed for several months; but because of the high-speed computation, a day of combat requires only a few minutes on the CDC 6400 computer.

BASIC MODEL STRUCTURE

Principal Decision Operations

As pointed out above, command decisions are continually being carried out in ATHENA. These decisions control the employment of all combat forces and the allocation of resources for both sides.

The way in which the model does this is shown in Figure 1. The primary inputs are (a) the objectives and resources allocated to the theater by the opposing nations, and (b) information on the outcome of brigade-level engagements. The primary outputs are the FEBA location, the condition or status of the opposing forces, and the consumption and/or depletion of resources.

Referring to Figure 1, periodically at each echelon an estimate of the situation is made, and, on the basis of this estimate, missions are selected and fire support is allocated to subordinate commands. This sequence continues down to brigade level, where the characteristics of each brigade engagement are established. These include the combat units from both sides, the missions of these units, and the terrain. An outcome is subsequently determined for each brigade engagement. The results of such an engagement are a local change in the FEBA and a degradation in the condition or status of the engaged forces, i.e., a loss of men and materiel and a consumption of supplies. The condition of the forces may then be enhanced, depending on the amounts of resources provided to them. These results are then aggregated at the various echelons, where they are used for the subsequent estimates of the situation.

For example, consider the box in Figure 1 labeled "Blue Corps Commander's Estimate" (of the situation). The army commander has assigned a sector and allocated certain fire support to the corps, and the corps commander must then consider how he can best make use of this support. Specifically, he must decide what mission to undertake, what sectors to assign his divisions, how to allocate his corps artillery and cavalry units among the divisions, and when and where to commit or reconstitute a corps reserve. He makes these decisions on the basis of his knowledge of his own forces, an estimate of enemy forces opposing him and their missions (the dashed line indicates imperfect intelligence), and calculations of various alternative results. The army commander went through such a process earlier, and the division commanders will make similar estimates as soon as they receive their fire-support allocation. (All "estimating" and "decision-making" operations, of course, are automated.)

The model consists, then, of a set of interlocking cycles, each cycle occurring with a frequency characteristic of that particular echelon. The principal model operations at each echelon are listed below, with the corresponding cycle periods shown in parentheses.

Theater (4 days)

Reinforcement artillery battalions assigned to armies
Air battle assessed
Close air support allocated to armies
Replacement personnel, equipment, and supplies allocated
Equipment repaired and wounded treated

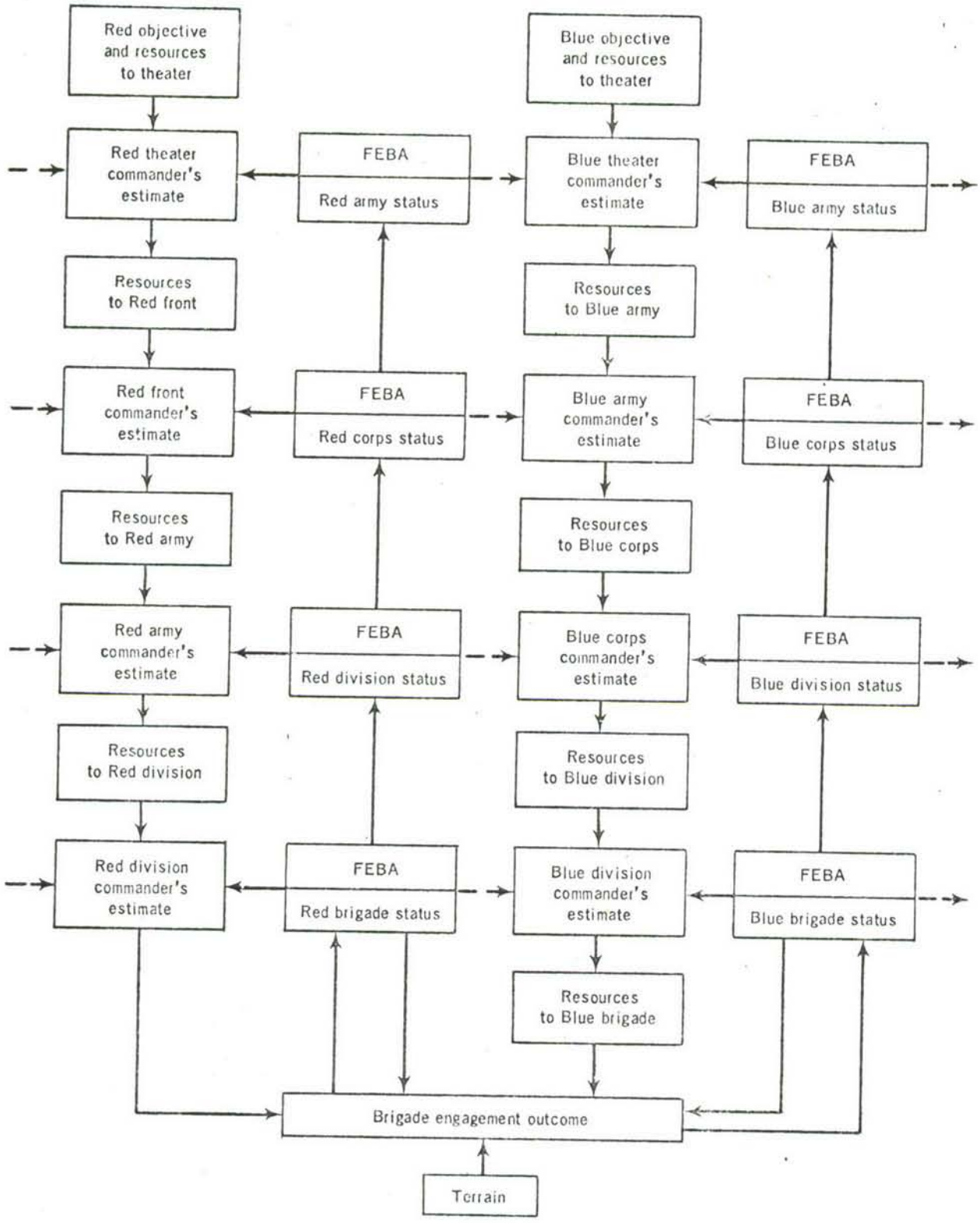


Fig. 1—ATHENA Outline

Note: Dashed lines indicate imperfect intelligence.

Army (2 days)

Reinforcement divisions assigned to corps
Mission selected and corps sectors assigned
General support artillery and close air support allocated to corps
Reserve corps assigned
Red divisions enter, leave unit replacement pool

Corps (1 day)

Mission selected and division sectors assigned
General support artillery, close air support, and corps cavalry elements allocated to divisions
Reserve division assigned

Division (12 hours)

Brigade mission selected
General support artillery, close air support, and cavalry elements allocated to brigades
Ground battle assessed
Replacement personnel, equipment, and supplies assimilated by brigade

Air warfare effects are simulated in ATHENA, although not indicated explicitly in Figure 1. The major roles consistent with tactical air doctrine are incorporated, together with a set of rules for the periodic allocation of available aircraft to these roles according to the progress of the air battle. Operations in the designated roles influence the air-to-air battle, speed of movement of supplies and reserve units, outcomes of individual brigade-level engagements, and subsequent role allocation of aircraft. The tactical air simulation is described in more detail in a later section.

Engagements

Combat forces—resolved to brigade level for Blue and division level for Red—are deployed on a map in which the terrain is resolved into four types, depending on the maneuverability of forces. Type A, for example, affords good cross-country mobility to vehicles, whereas vehicles in Type C terrain are generally road-bound. Type D represents important obstacles that would impose a delay to advancing forces, such as large rivers.

In deploying the opposing forces along the initial FEBA, it is not necessary to align the forces such that their organizational boundaries line up across the FEBA. It is necessary, however, to construct streamlines from one end of the battlefield to the other that roughly constrain the flow of forces toward (or away from) their theater objective. This is an important step, because, although there is some lateral movement of forces across these streamlines behind the FEBA—resulting from the commitment and reconstitution of reserves, changing sector assignments, the arrival of reinforcements, and the Red division replacement policy—the model does not recognize combat nor permit movement in the face

of the enemy across these streamlines. The realism of the action therefore depends a great deal on the accuracy with which the planner can predict the real life flow of the forces.

Once the war starts, combat is assessed periodically across the front in a series of engagements of approximately brigade level. The characteristics of each of these engagements include the type of terrain, the type of defensive position (if appropriate), the combat units involved, their missions, and their current status in terms of personnel, major weapons, and supplies on hand. The Blue brigades involved receive varying amounts of support as allocated to them from division and corps cavalry units (which include attack helicopters), division and corps artillery, and close air support. The Red force is treated in a similar, but less detailed fashion.

From the above components, an effective firepower array for each side is constructed for the type of engagement in question, and this firepower array is used in calculating engagement results. Each array represents firepower from six source-classes that could be delivered effectively against three target-classes in this particular type of engagement. The six source-classes are heavy armor vehicles, light armor vehicles, personnel-carried weapons, helicopters, support artillery, and (fixed-wing) close air support. The firepower from each of these is categorized by its capability against the three target-classes, which include heavy armored tanks, light armor vehicles, and personnel. Before the firepower is applied to the targets, it is modified to reflect the effects of the type of terrain over which the engagement is taking place.

The results of each engagement are calculated from algorithms that take into account both the firepower by target-class and targets present in that class. Equipment losses and personnel casualties are produced directly, and the local FEBA change is based on a weighted force ratio calculated by matching the total effective firepower arrays against the mix of targets present. Supply consumption is then determined for the participating units for the three classes of ammunition, POL, and other supplies.

Status File Relationships

In order to accomplish the above operations, current inventories of all affected items must be maintained. The relationships in maintaining these inventories—in the form of individual unit status files—help to depict (1) how the combat capability of a unit is determined, (2) how casualties to personnel and equipment are managed, and (3) how replacements and resupply are handled.

Figure 2 is a schematic of the status file relationships. The status file contains the current quantities of the items shown—personnel, ammunition, POL, and other supplies, along with all major items of equipment. This is maintained for each Blue brigade and cavalry unit, and for each Red division.

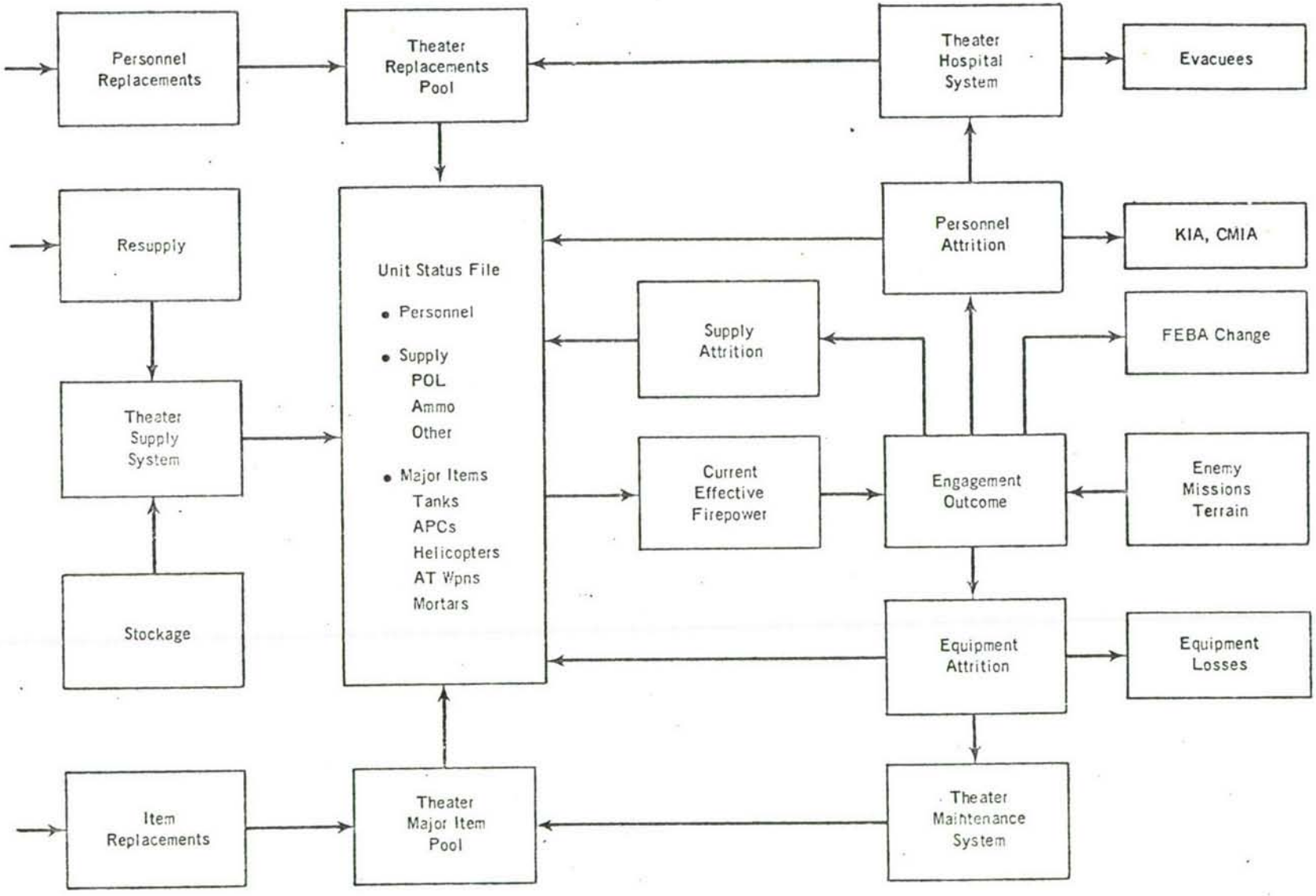


Fig. 2—Status File Relationships

The effective firepower of each unit is developed from its status file. For all weapons currently in the status file, the nominal firepower values are selected from inputs according to the type of engagement underway. The demand by these weapons for ammunition, POL, and other supplies for this type of engagement is then compared to the availability of these supplies in the unit at this time. If availability is limited, then the nominal firepower values are adjusted downward to reflect the effect that limited supplies would have on each weapon's capability to perform in combat. This effective firepower is then a contributing factor in deciding which mission to undertake, and it subsequently represents the full combat capability of this unit in any upcoming engagement.

Although it is one of the smaller boxes on this figure, the engagement outcome is the central event. The inputs to the engagement outcome include the current effective firepower arrays for those units involved on both sides, the missions of those units on both sides, and the terrain. The outputs include the change in the local FEBA and the attrition of personnel, supply, and equipment. By attrition, we are referring to all personnel and materiel that are temporarily or permanently removed from the unit status file.

The arrows leading from the three attrition boxes back to the status file indicate the updating of the status file to reflect this attrition of personnel, supplies, and equipment.

Certain irretrievable losses of personnel (those killed in action and those captured and missing in action) and equipment, which are included in the attrition, are permanently removed as shown on the right side of the figure. Wounded personnel are removed to the fixed-bed hospitals. Depending on the evacuation policy, certain of these will be evacuated while the remainder are sent to the theater replacement pool following recovery. An average recovery period is employed, the duration of which depends on the applied evacuation policy.

Damaged equipment is removed for support maintenance. Delay times are applied, depending on the support maintenance capabilities for each type of equipment, between the time such equipment is damaged and the time it arrives at the theater equipment replacement pool.

Shortages of personnel, supplies, and equipment in the unit status files are filled according to the theater availability of such items and the relative shortages existing in the status files for all units within the force.

Division Cycle

A complete description of ATHENA operations is beyond the scope of this paper. As a matter of interest, however, in this section the division cycle is described for the Blue side in greater detail, with emphasis on the estimate of the situation and associated decision-making.

Principal Steps. At the beginning of the cycle the division is assigned a sector and given an allocation of cavalry and fire support by corps (based on the corps estimate of the situation). The fire support consists of a number of general support artillery battalions and a number of close air support sorties.

In the next step the division estimate of the situation is made, followed by decisions concerning brigade missions, allocation of cavalry and fire support, and commitment or reconstitution of the division reserve. This step is described in greater detail below.

These decisions by the opposing forces are sufficient for all the engagement characteristics to be specified, and the engagement results are then computed.

Finally, the division receives an allocation of replacements and resupply and reallocates them among its brigades; and the next cycle can begin.

Division Estimate. The estimate of the situation consists of a series of estimated engagement outcomes, based on various hypothetical circumstances. For each brigade on line, the division commander estimates the threat, then asks and answers several "What if" questions.

For each brigade in each hypothetical engagement, the expected engagement characteristics must be established. The commander begins by considering an attack mission for the brigade; and he knows the current status of the brigade and the number of artillery battalions normally in direct support of the brigade.

Next he estimates the corresponding information about the enemy. Estimating an enemy mission is complicated by the fact that a brigade may face elements of more than one division, having different missions. The enemy mission is estimated to be the same as it was last period, provided that it was the same for all units faced. If it was not the same for all enemy units, then a cautious estimate is made. That is, if the assumed brigade mission is attack, then the enemy mission is estimated to be defense; and if the brigade mission is defense or delay, then the enemy mission is estimated to be attack.

In estimating the numbers of enemy combat units of each type, a weighted average is taken of the numbers of each type actually faced in the past two periods. The weighting factors are related to the intelligence capability of the force.

Whenever a unit mission is assumed (or estimated) to be defense, then the type of defensive position must be determined (or estimated). This is done by examining the average FEBA movement across the unit front during the past several periods and comparing it with a threshold. If the actual movement was less than the threshold value, then the unit is considered to have had time to prepare good defensive positions; otherwise, the defense is characterized as hasty. The value used for the threshold depends on the engineer capability of the unit.

Once all the characteristics of the hypothetical engagement have been ascertained, the anticipated outcome is computed as if this were an actual engagement.

Next, this entire process is repeated three times—each case corresponding to an option open to the division commander. First, he allows the artillery in direct support of the brigade to fire at an increased rate. Second, he assigns a reinforcing role to a fraction of the corps artillery in general support of his divisions. And third, he commits the reserve brigade, dividing up the original brigade frontage. The final result of the estimate of the situation, then, is an estimated outcome for each of these four sets of conditions.

Division Decisions. The most favorable of the four outcomes is identified, together with the least support required to achieve this outcome. If all the outcomes are unfavorable, then a brigade mission one step lower on the aggressiveness scale is considered, and the estimating sequence is repeated. Otherwise the brigade is assigned the assumed mission and is allocated the minimum support needed to achieve the best expected outcome.

The discussion above was based on the assumption that the division has two brigades on line and one in reserve. In case the division has all three brigades on line, one of them is virtually withdrawn and the estimate of the situation is made in the normal way. If the estimate and resulting decisions do not lead to reserve commitment, then the virtual withdrawal becomes actual, and the withdrawn brigade becomes the division reserve. If the estimate does lead to reserve commitment, then the brigade is not withdrawn.

After these decisions concerning the ground forces have been made, the tactical air sorties available for support of the division are allocated. (Note that tactical air played no part in the estimate of the situation.) Generally speaking, close air support sorties are allocated to engaged brigades so as to support strength on offense and weakness on defense.

General Features of Tactical Air Cycle

The principal function of the tactical air cycle in ATHENA is to develop a dynamic distribution of close air support aircraft that are available for allocation by the land forces. For this reason, the representation of the tactical air battle is much more highly aggregated than is the representation of the land battle. For example, notional type aircraft are employed, and a less sophisticated decision routine is included to manage the allocation of aircraft to the various roles.

The general features of the tactical air cycle are shown in Figure 3. Aircraft are allocated to roles on a theater-wide basis according to an input strategy that is designed to direct efforts towards existing needs. Operations in the designated roles produce outputs, which in turn affect the course of the air battle, the outcomes of individual brigade engagements, and subsequent aircraft role allocations. The decisions regarding

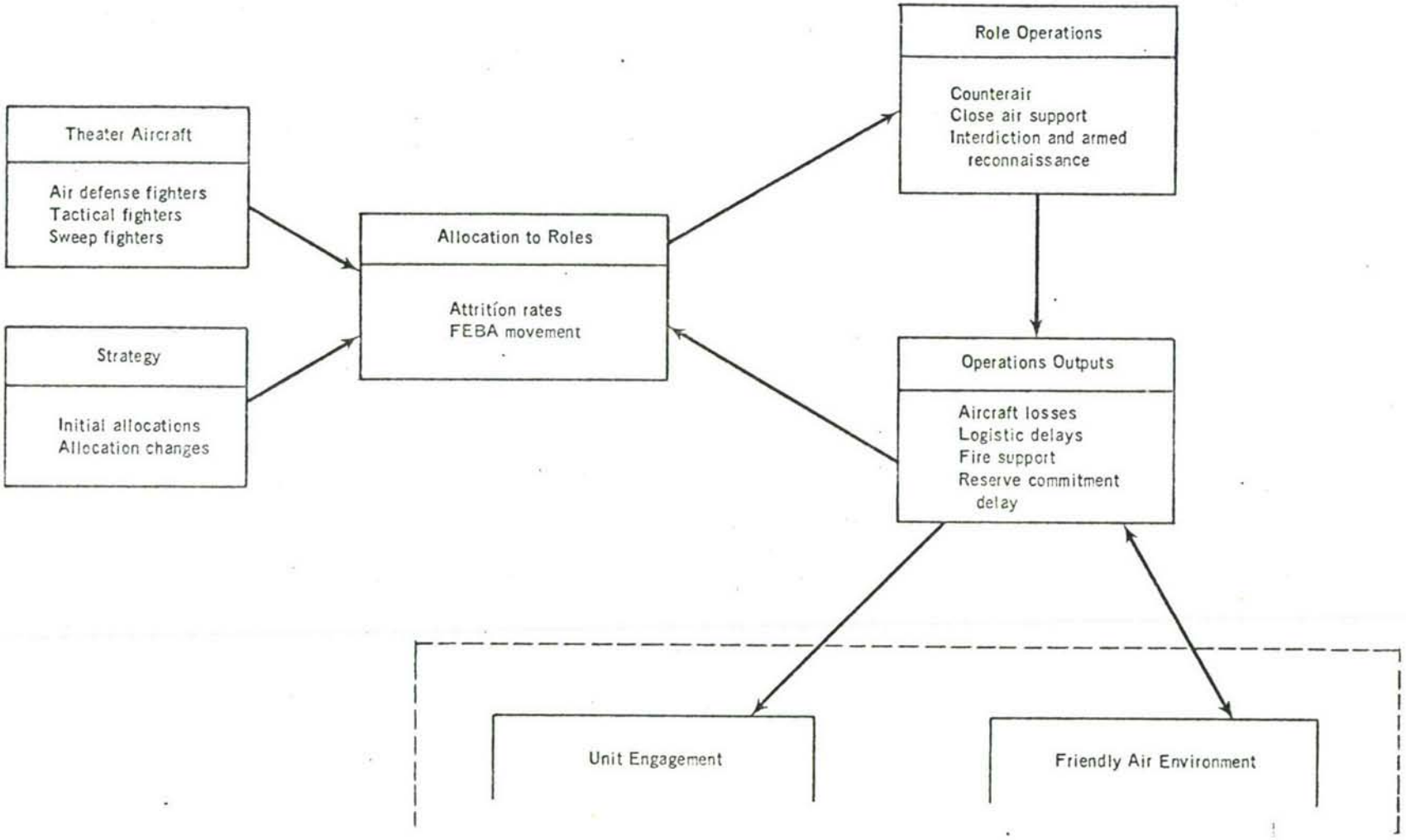


Fig. 3—Tactical Air Submodel

aircraft allocation are performed at theater level. Role operations are examined prior to subsequent allocations.

All aircraft in the theater are represented by three composite or notional types. One of these is the air defense fighter (ADF) which includes those aircraft assigned to the role of air-to-air defense. A second type is the tactical fighter (TF) which includes those aircraft assigned to the remaining roles of attacking ground targets in enemy territory and in support of the friendly ground forces. The third type of aircraft is the sweep fighter (SF), which includes those aircraft armed for air-to-air combat and assigned to accompany and provide air-to-air protection of TF aircraft while penetrating enemy air-to-air defenses.

Four roles are considered to which the flyable aircraft are allocated. These are:

Air defense interceptor (ADI). Aircraft in this role operate with the theater air defense system to engage enemy aircraft when they penetrate friendly airspace.

Counter-air (CA). This is an offensive role to destroy enemy aircraft while parked on the airbases, enemy airbase facilities, surface-to-air missile (SAM) sites, and any other enemy systems which seriously threaten friendly air operations.

Close air support (CAS). This role includes all strikes in support of ground forces under control of Division Air Liaison Officer.

Armed reconnaissance and interdiction (AR/I). This role includes aircraft penetrating enemy airspace to destroy fixed and moving targets of general military significance.

As mentioned above, decisions are made at the theater level. Initial allocations to be applied to each role are provided as inputs, and these are adjusted in the subsequent periods according to aircraft loss rates that occur in the air and on the ground. The goal is to contain loss rates within certain specified limits, which in turn represent maximum rates of air and ground losses above which sustained operations are in serious jeopardy. Allowance is made, however, to radically alter the allocation percentages so as to bring greater effort in support of the ground forces if the FEBA is moving backwards at some rapid rate.

The ADF aircraft type is not included in the above allocation, but is handled separately. Although some of these aircraft, in reality, may have reasonable air-to-ground capability, they are generally configured specifically for air-to-air combat and perform that role much better than can the TF aircraft.

The "action" in each role is handled independently of the other roles. Aircraft allocated to the ADI, CA, and AR/I roles work through

air submodel routines, but aircraft allocated to CAS are supplied to the ground forces for distribution and application as support to the ground forces.

The CA role has the primary objective of attacking enemy air capability at its source of operations. Associated with this is also the task of attacking enemy air defense capabilities that interfere with carrying out both the CA and AR/I roles. The effects of the CA role include the destruction of enemy aircraft and SAM sites. These affect the air battle primarily by reducing the threat to friendly air operations, but reducing the numbers of enemy aircraft also reduces the enemy CAS and AR/I threats.

The AR/I role activity consists of attacking fixed and mobile targets in enemy territory. Such targets are those considered militarily significant and exclusive of those designated for CA attack. Although AR/I role aircraft have the objective to destroy targets, the model does not handle target destruction explicitly in this role. In reality, the effects of destroying such targets are disruption and delays in rear area supply and troop movements. When reserves are committed above division level, for example, the execution of these decisions is delayed more or less depending on whether a friendly air environment exists. A friendly air environment exists for a side if the density of enemy AR/I sorties over that side's territory is below a certain threshold. But if the density is above that threshold, a friendly air environment does not exist, and ground movements of men and supplies are consequently slowed down.

The ADI role has the objective of intercepting incoming enemy aircraft over friendly territory. Small penetrations over enemy territory may take place if interceptions occur near the FEBA, but penetration would not normally be considered part of the role.

Finally, the CAS role activity is handled by the ground force part of the model. Distribution of aircraft to combat units is accommodated, and the contribution of fire support made to engagement outcomes is counted.

MEASURES OF FORCE PERFORMANCE

Force performance measures produced by ATHENA include the movement of the FEBA, casualties, major weapon losses, and supply consumption. The location of the FEBA along the entire front is provided following every division cycle to reflect the movement accomplished by the many engagements that have just occurred. Casualties are reported from both combat and non-combat causes, to include those killed, wounded, and captured. These numbers not only reflect the intensity of the battle, but indicate the required hospital capacity for the theater.

Major weapon losses are reported by type weapon. Details are also provided regarding the ability of the maintenance system to handle the repair loads that are produced.

Supply consumption is produced for three classes of supply—POL, ammunition, and other supply. This consumption reflects actual expenditures for all units engaged in combat, and thus depends on the numbers of weapons and personnel engaged as well as the intensity of combat.

ATHENA also produces an indicator of the residual combat capability of the force. This is a relative measure, expressed as the percentage of the authorized firepower that currently remains in the force.

One further indicator of the pace of combat produced by ATHENA is a frequency distribution of the types of engagements experienced by the Blue maneuver units. From this, it is possible to observe, for example, the amount of time units are engaged in active combat in relation to the time they are in static situations or in reserve.

APPLICATIONS

ATHENA measures the performance of a theater force in combat, and it relates this performance to literally thousands of input variables. In particular, it relates force performance to the mix of combat battalions on both sides and the mix of major weapon systems on both sides; this was one of the model's original purposes.

In addition, however, the effects on force performance of certain changes in tactical doctrine can be measured. For example, alternative policies for the use of reserve units can be examined by varying the conditions under which reserves would be committed and reconstituted. Of equal interest is the representation of force aggressiveness and its influence on force performance. Varying degrees of aggressiveness can be simulated by causing systematic over- or underestimation of enemy strength in the estimates of the situation.

Force performance is also related to combat support capabilities and employment. Alternative policies of artillery and tac air employment can easily be studied, for example, and the model dynamically represents the capabilities of combat engineers to construct barriers and the effects of these barriers on the course of the war.

Finally, force performance also depends on logistic support capabilities and policies, among which are the medical evacuation policy, personnel and materiel replacement rates, and maintenance capabilities. All of these can have a strong influence on the course and outcome of a campaign.

Thus for the first time ATHENA provides an opportunity to explore by simulation the effects on combat success in a theater war of alternate combat organizations, weapons, and doctrine. In doing so, it gives the proper preeminent position to firepower but includes the influence of other combat functions more effectively than any previous model.

REFERENCE

General Research Corporation, "Conceptual Design for the Army in the Field Alternative Force Evaluation, CONAF Evaluation Model IV, Part 1—Model Description," OAD-CR-60, September 1974. UNCLASSIFIED

JANUARY 1973

NOW DATED IN REGARD TO DETAILS OF COMANEX

A HIERARCHY OF COMBAT ANALYSIS MODELS

by

GAMING AND SIMULATIONS DEPARTMENT

GENERAL RESEARCH CORPORATION
OPERATIONS ANALYSIS DIVISION
WESTGATE RESEARCH PARK, McLEAN, VIRGINIA 22101

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FOREWORD

This brochure briefly describes the nature, scope, interrelations, and applications of the family of ground combat analysis models under continuous development by the Gaming and Simulations Department of the General Research Corporation Operations Analysis Division. Several of these models were originally developed in support of specific Army analytic tasks and have evolved over the years more-or-less independently of each other. In the past 3 years, however, the major methodological emphasis in this department has been on integrating the separate models into a hierarchy of combat assessments. Thus, the more detailed models of combat at lower echelons—platoon and company e.g.—can "feed" higher echelon games or simulations—brigades or divisions—with close combat assessments inherently more credible than traditional "index of combat effectiveness" inputs.

The respective models are described herein in rough order of ascending model aggregation. Several illustrative hierarchical linkages are also demonstrated and various applications outlined.

Detailed briefings on the models and their uses are available on request. Documentation for most of the models is available in DDC and is cited in the bibliography.

Lawrence J. Dondero

LAWRENCE J. DONDERO, Director
Gaming and Simulations Department

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APPENDIX B: BIBLIOGRAPHY

1

CARMONETTE

CARMONETTE is a computerized Monte Carlo simulation of battalion sized or lower units in ground combat (Figure 1-1).

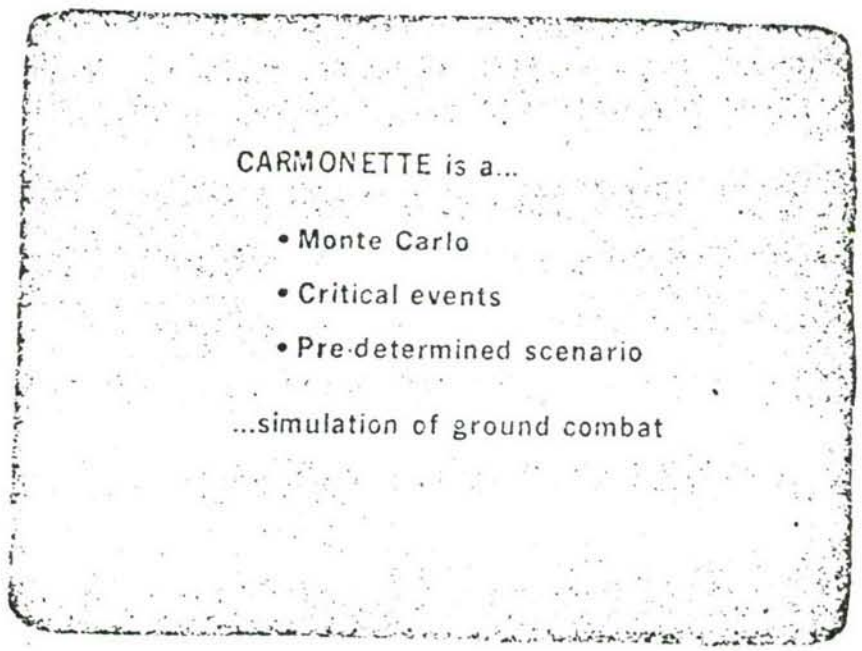


Figure 1-1

Its primary activities are the movement of units, the detection of targets, and the firing of weapons (Figure 1-2).

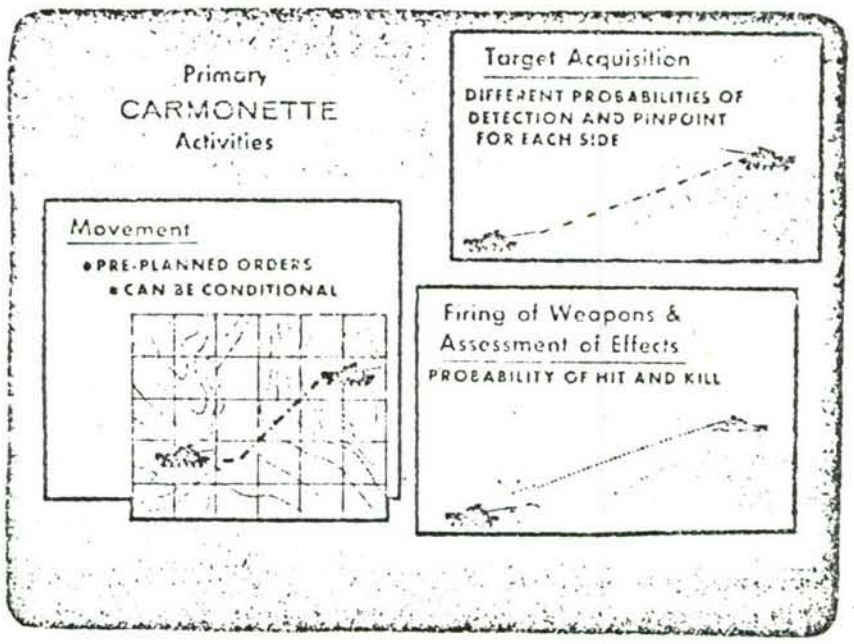


Figure 1-2

Unit resolution can be an individual soldier, a tank, a squad, or a platoon, and each side can have up to 48 units. CARMONETTE is a critical event game with time recorded to 1/10,000th of a minute. The map grid size is selectable but a 100-meter grid on a 6.0 by 6.3 km total map area is normally used (Figure 1-3).

CARMONETTE can play up to 54 weapon types including indirect fire artillery and mortars and direct fire weapons with either fragmenting or solid munitions (Figure 1-4).

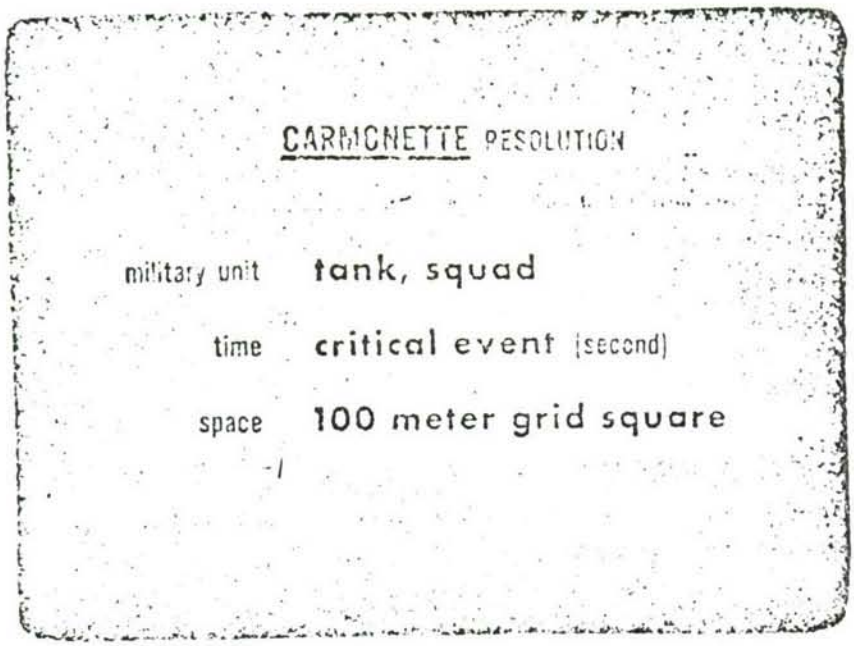


Figure 1-3

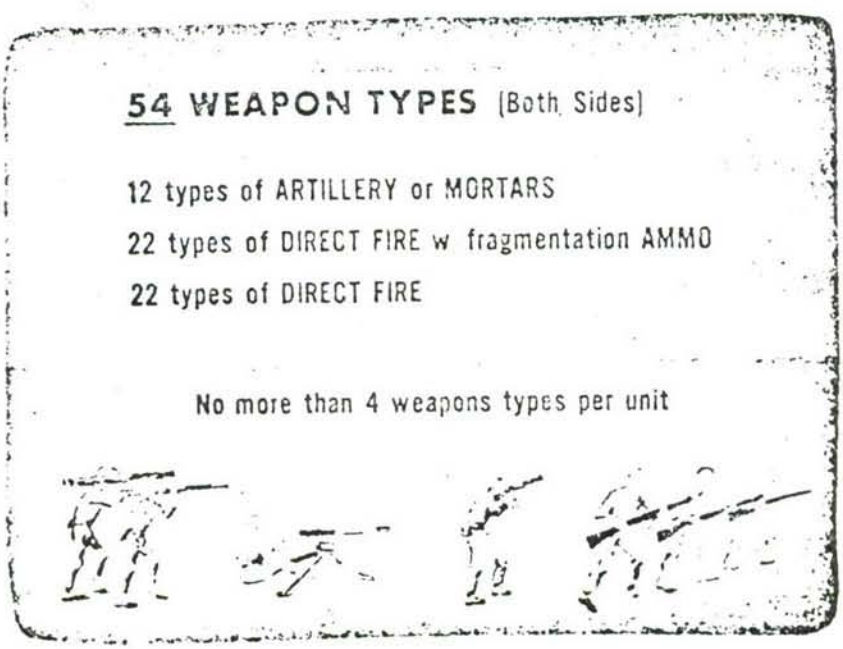


Figure 1-4

Input requirements include detailed descriptions of the units being played, performance characteristics of the various weapon types, a set of orders for each unit based on tactical doctrine in accordance with a predetermined scenario, target detection probabilities, and a detailed description of the terrain (Figure 1-5).

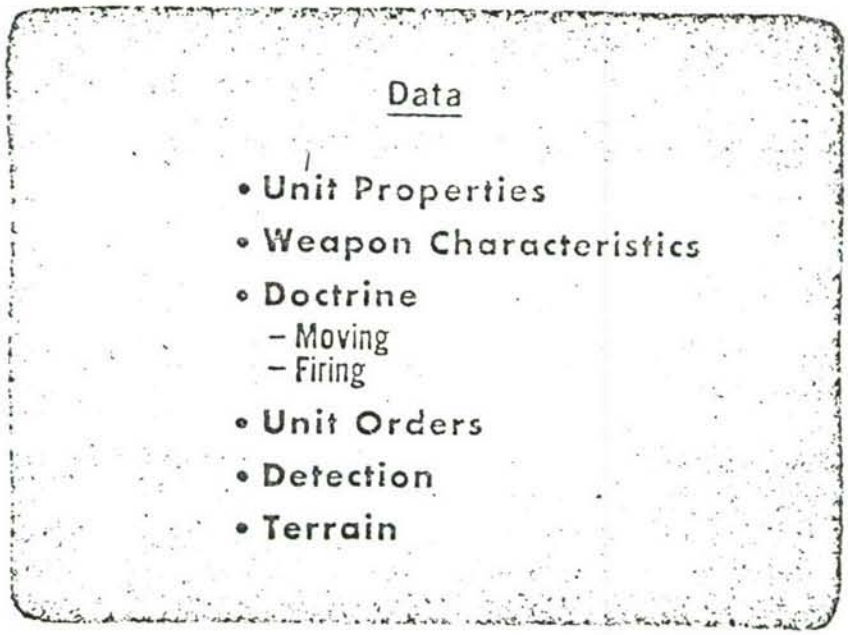


Figure 1-5

The terrain inputs required for each grid square are average elevation, height of vegetation, indexes of cover and concealment, and road and cross-country trafficability (Figure 1-6).

The basic output of a CARMONETTE run is a computer listing of every event assessed during the simulation battle and includes the elements killed, various operational statistics, and data relevant to engagement ranges. Summary routines collect and collate these data on the various actions in the battle for analysis of the results (Figure 1-7).

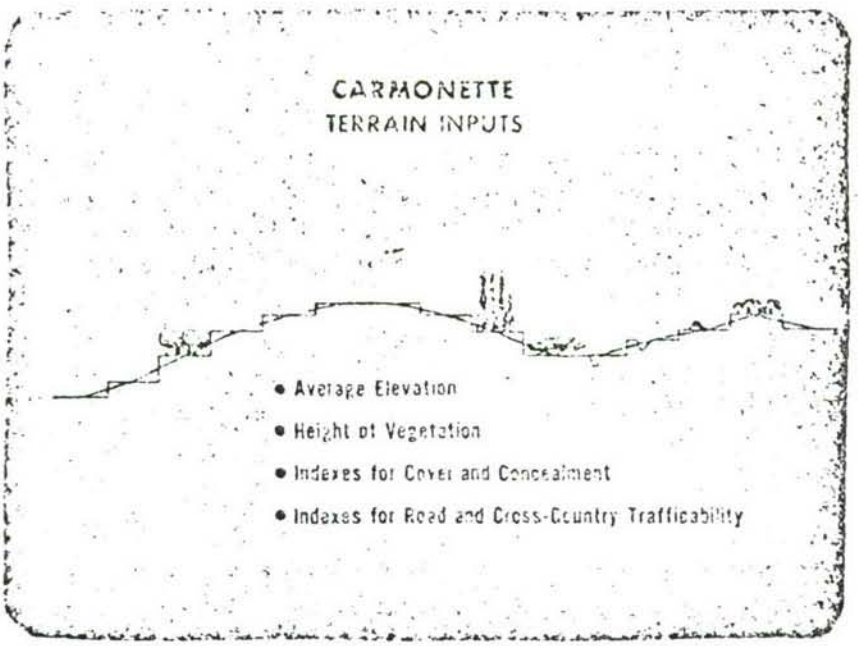


Figure 1-6

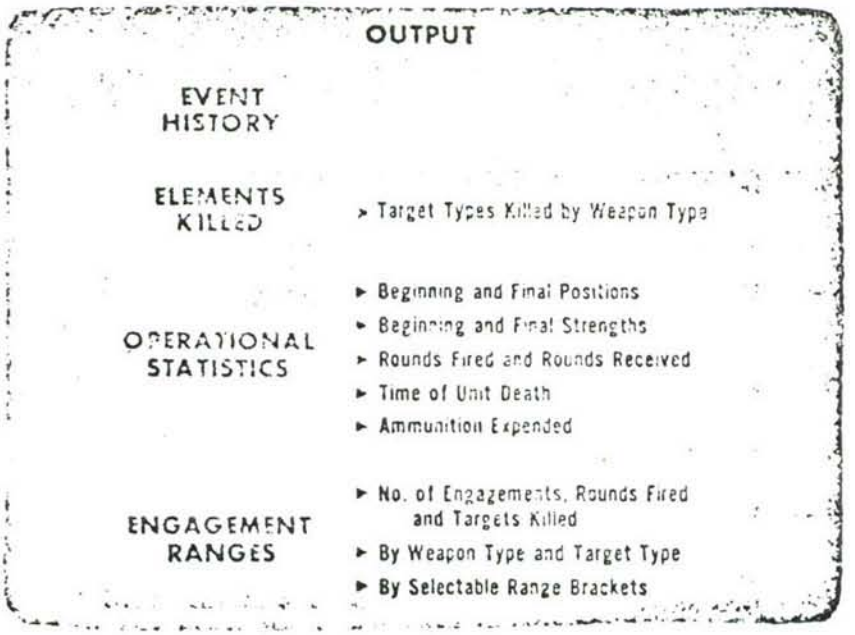


Figure 1-7

Figure 1-8 shows examples of the types of history messages concerning a weapon firing event that might appear in a game output. Each line message includes the side, unit number, time of the event, coordinates of unit location, and identification of the message type. In the Position Disclosure (PSN DSCL) message the numbers following I1 to I3 and I3 to I4 identify the opposing units that detected the muzzle flash on firing.

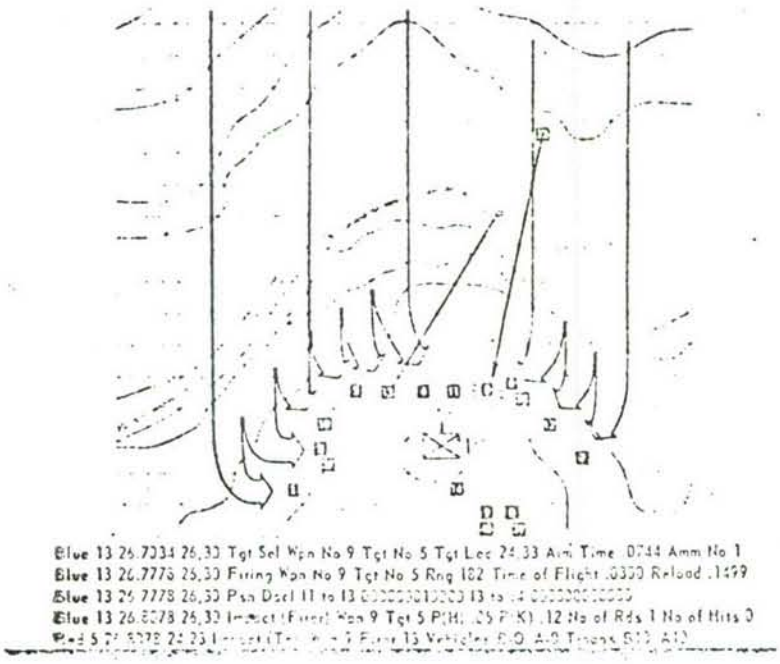


Figure 1-8

CARMONETTE can be used in the solution of various problems. For example, it was used in the Equal Cost Firepower studies (ECF I and II) done for USA ACSFOR to compare the effectiveness of different equal cost mixes of antitank weapons. In a study done for HQ ECOM, it was used to evaluate the effectiveness of low-level units equipped with various night-vision devices (Figure 1-9).

CARMONETTE has also been used to produce casualty assessment data for various mixes of opposing units and the data generated then utilized to assess battle outcomes in a division level war game.

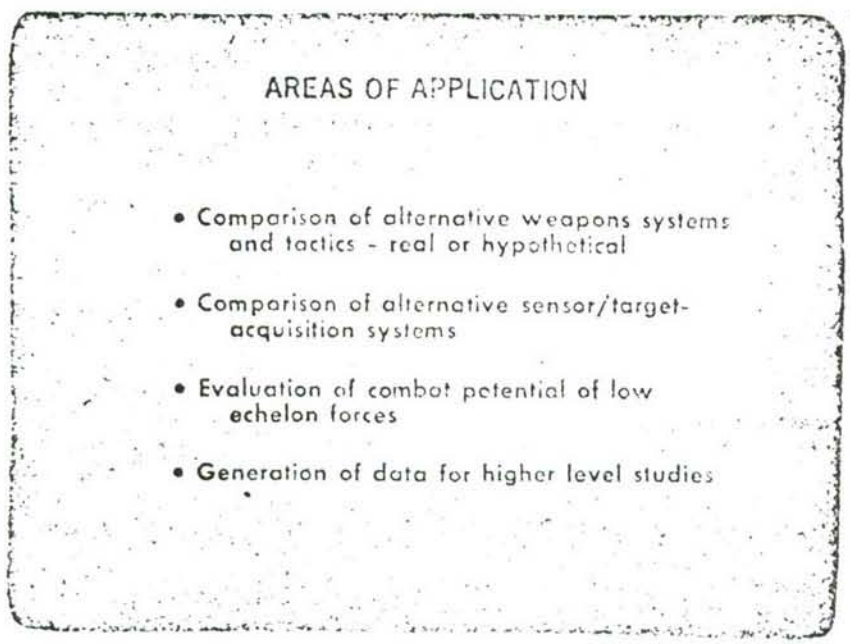

AREAS OF APPLICATION
• Comparison of alternative weapons systems and tactics - real or hypothetical
• Comparison of alternative sensor/target-acquisition systems
• Evaluation of combat potential of low echelon forces
• Generation of data for higher level studies

Figure 1-9

2

DETERMINISTIC END GAME ASSESSMENT SIMULATION (DEGAS)

DEGAS is a computerized simulation designed to produce estimates of the results of hostile encounters essentially isolated from the general context of battle and involving relatively few participants on each side.

Figure 2-1 shows a typical situation that might be represented in this model. In fact, the model was developed as part of the current SCAT-II study, whose principal concern is the investigation of the combat effectiveness of Army helicopters.

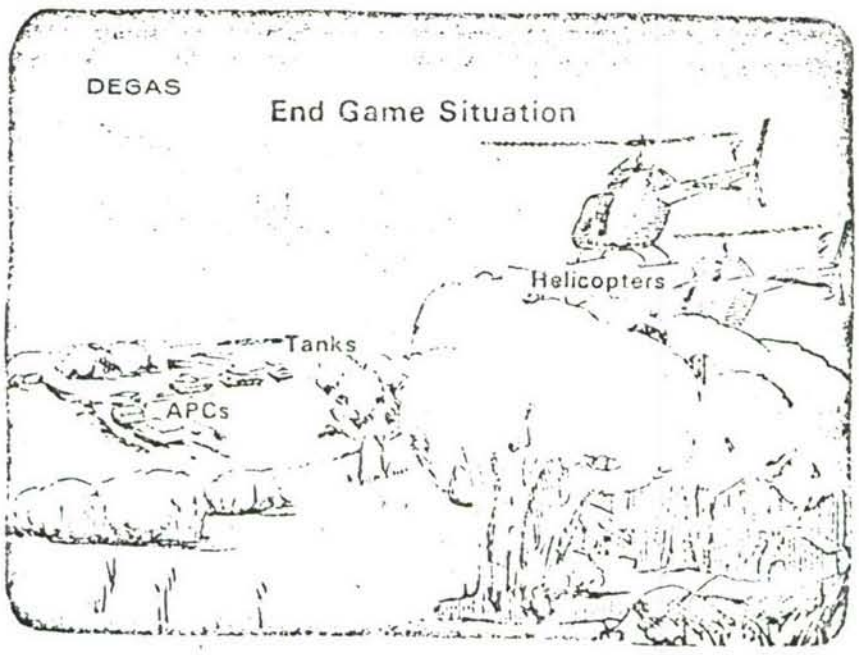


Figure 2-1

In its present usage, the model simulates engagements involving a maximum of six helicopters attacking a ground target complex having a maximum of 16 elements. The time duration of the simulated engagement is limited to about 10 minutes.

Figure 2-2 shows the inputs required by the model. In its present application, the airborne weapons represented in the model include the TOW missile, HELLFIRE, the 30mm, the MINITAT, and 2.75-inch rockets. Ground weapons represented include air defense weapons and missiles, tank main armament, and small arms.

Vulnerable areas for each helicopter and each armored ground element for each opposing weapon are input. In the case of personnel targets, lethal areas of munitions are input.

Movement paths, movement rates, and line-of-sight conditions are input for each participating element for the total duration of the simulated engagement.

Tactics and target priority and selection rules are input by a combination of the model logic and input variables.

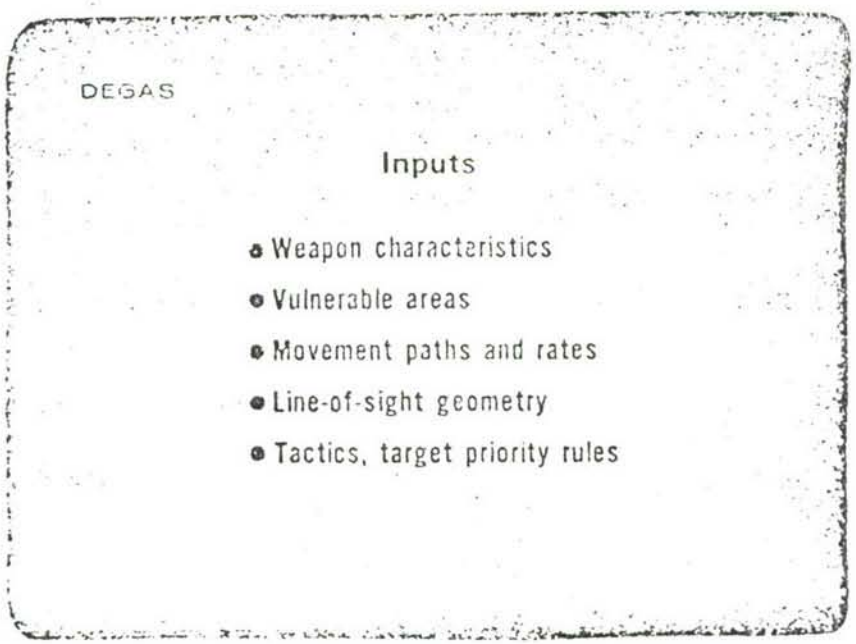


Figure 2-2

The general form of the model logic is shown in Figure 2-3. Target selection is based on input target priorities and is influenced by range and line-of-sight conditions as these conditions vary during the simulated engagement. The time simulated by the basic game loop shown in this figure is a quarter of a second. That is, these activities occur four times during each simulated second of the action:

1. The position (X,Y,Z coordinates) of each attacker and each defender is updated.

2. Line of sight to selected targets is checked.

3. Attackers and defenders fire (as appropriate).

4. Damage to each attacker and each defender is assessed.

5. Target priorities are reassessed (depending on the input engagement rules) and, if appropriate, a new target is selected.

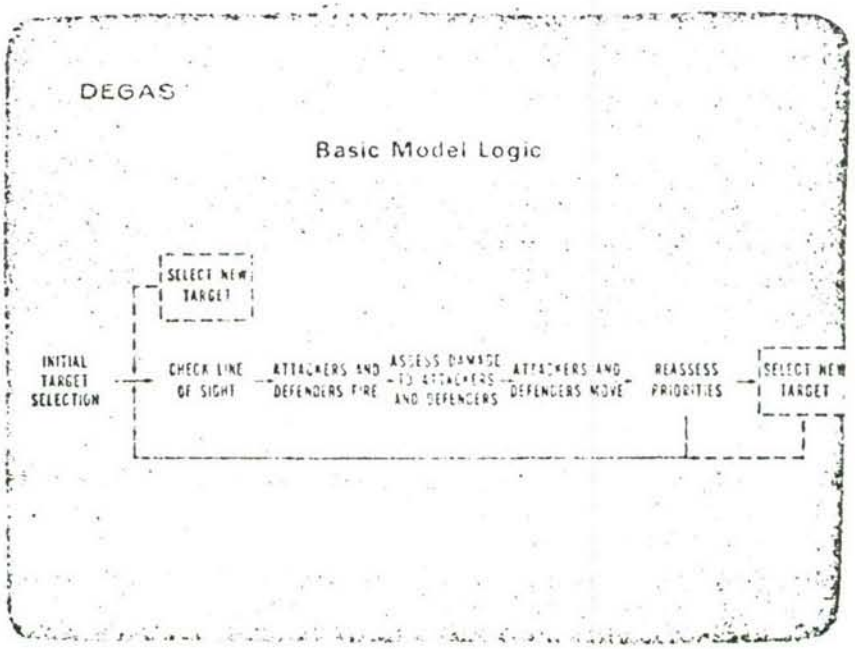


Figure 2-3

This sequence is about what would be expected in a Monte Carlo combat simulation of this scope. The important difference is that Monte Carlo techniques are not used in this model. No random numbers are called. This is a dynamic deterministic model and the engagement results it produces approximate the average results that would be produced by many replications of a comparable Monte Carlo simulation.

The output estimates produced by DEGAS are shown in Figure 2-4. In our present use of the model three categories of helicopter kill are reported: mission abort ("C" Kill), forced landing ("B" Kill), and catastrophic kill ("A" Kill). A single kill category for ground armored vehicles is reported. Personnel casualties and ammunition expenditures on both sides can also be reported. The elapsed time of the engagement is the final output.

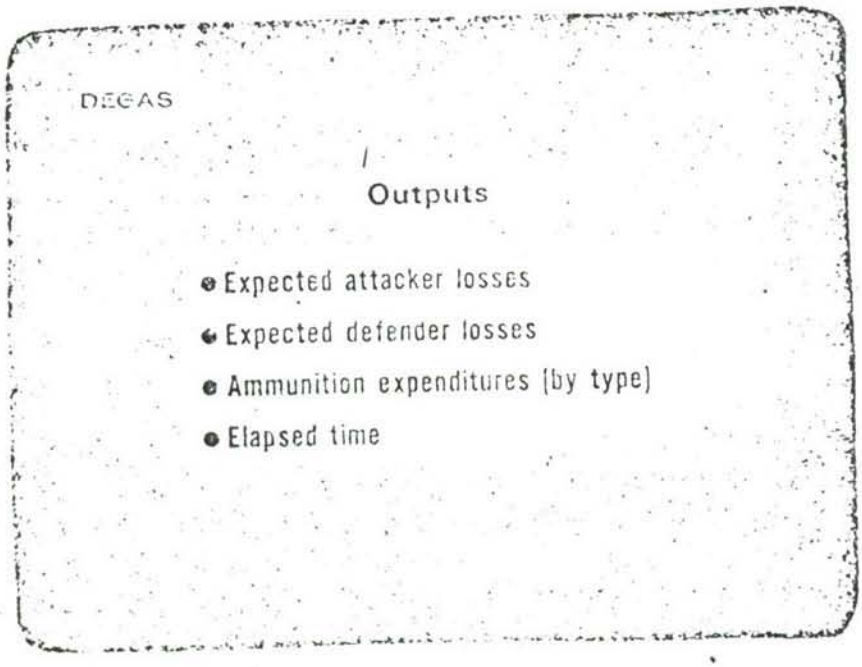


Figure 2-4

The features of the DEGAS model deserving particular emphasis are summarized in Figure 2-5.

First of all, the model is applicable only to the so-called "end game." That is, it is applicable only to actions that occur in relative isolation from the general context of battle and involve relatively few participants on each side. The model is also limited in its ability to represent contingent decisions that might occur within the dynamics of the engagement.

However, this model can produce estimates of the narrow context end game results for a small fraction of what a stable Monte Carlo solution would cost because it produces its estimates of the engagement outcome by a single simulation run. This makes feasible a wider range of

investigations than would be possible if multiple replications of each situation were required.

The DEGAS model is quite sensitive to small variations of input materiel characteristics or tactics. This permits evaluation of the consequences of input variations not practicable with a Monte Carlo simulation.

To illustrate the advantage, in certain situations, of the deterministic model over the stochastic model, consider the tactic of an attack helicopter engaging an armored ground target. What is the optimum range of engagement with respect, say, to the resulting exchange rates. An increase in range tends, of course, to degrade the effectiveness of the ground weapons firing at the helicopter. On the other hand, an increase in range of engagement may increase the time required for the helicopter to detect and acquire a ground target, and thus increase the time of exposure of the helicopter to ground weapons. With a deterministic model such as DEGAS it is practicable to simulate the engagement repeatedly, varying the engagement range with each repetition, and thus determine the range at which the exchange rate is optimum. To accomplish this with a stochastic model would require many replications of the simulation for each variation of engagement range, and the solution produced would still contain the "noise" element that is characteristic of Monte Carlo solutions.

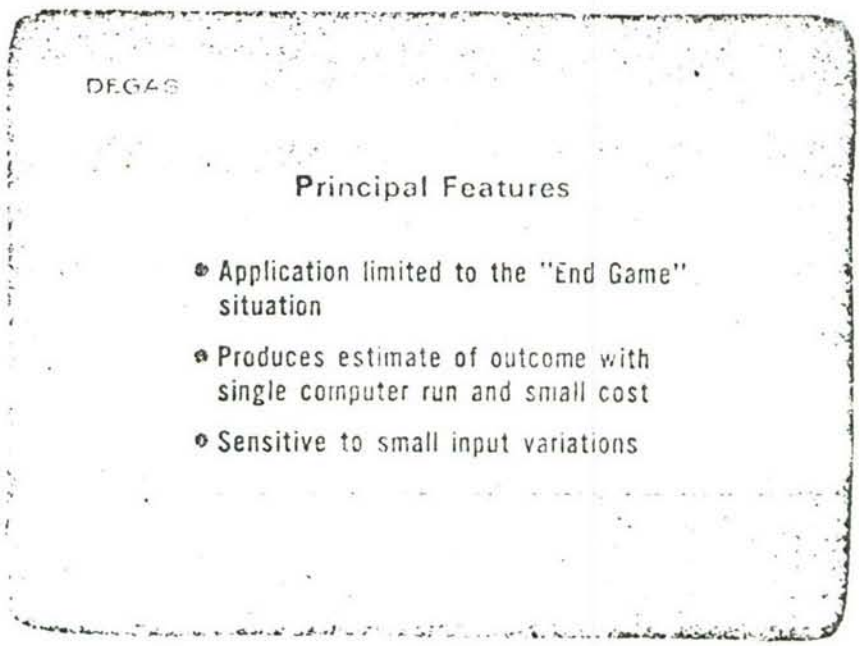


Figure 2-5

3

COMANEX

During the past several months the Gaming and Simulations Department has been working on the problem of adapting, modifying, and implementing the COMAN model for use in various departmental studies. The COMAN (COMbat ANalysis) model was developed by Dr. Gordon M. Clark at Ohio State University. It was the subject of his doctoral dissertation published in 1970. A modified version of the model has been implemented at GRC on the CDC 6400 computer. The model is operational; it has been assigned the acronym COMANEX (COMAN EXtended). We would like to give you a general idea of what the model is, what it does, and how it does it.

COMANEX is a stochastic model based on Dr. Clark's extensions of the classical Lanchester theory of combat. It is a satellite model; it must be used in conjunction with a high resolution combat simulation model. Its primary function is to take the results of the high resolution model, in terms of numbers and types of casualties for a given force mix, and extrapolate these results to other force mixes not evaluated explicitly by the high resolution model. The extrapolation process can be performed at a tiny fraction of the cost that would otherwise be incurred if the high resolution model itself were used for the evaluation. The short running time of COMANEX also makes it feasible to use the model for directly assessing close combat engagements in division level games as part of the overall assessment routine. Indeed, we are currently using the model for that purpose in DBM applications in SCAT II and COMCAP II.

COMANEX comprises two basic sub-programs—the pre-processor and the simulator. Figure 3-1 illustrates how these programs are used with CARMONETTE serving as the high resolution model.

Data relating to weapons characteristics, combat environment, mission, etc., for a particular mix of opposing forces are input to CARMONETTE. CARMONETTE performs a pre-specified number of replications of the battle. It then outputs, for each replication, a time-sequenced casualty history identifying the time at which a casualty occurred, the casualty type and the killer type. This output is, in turn, input to the COMANEX pre-processor. The pre-processor massages the data and outputs a set of Lanchester-type parameters which represent, essentially, the kill rates for each firer/target combination in the battle. The parameters are then

stored in the COMANEX simulator to be subsequently used in predicting the outcomes of battles involving mixes "close" to the original mix (mixes involving the same types but different numbers of weapons).

The mixes to be analyzed are specified and input to the simulator. In practice, for test purposes, the first such mix is the original one from which the Lanchester-type parameters were calculated. The simulator is exercised for up to 100 replications of the battle. It outputs the expected results of the battle in the form of killer/casualty matrices which list the number of casualties, averaged over all replications, by time period, for each of the target types, for each of the killer types. After verifying that the simulator reproduces the results of the original CARMONETTE run, the remaining mixes are processed and their expected outcomes are listed, again in the form of killer/casualty matrices.

It should be noted that in all cases tested thus far the simulator does indeed reproduce, with a high degree of accuracy, the results of the CARMONETTE runs from which the Lanchester-type parameters were extracted. We have had some success in extrapolating to other force mixes. Additional testing is being conducted to determine the maximum extent to which the results may be accurately extrapolated. We do not know, as yet, how far we can "stray" from the original mix and still obtain reasonable results.

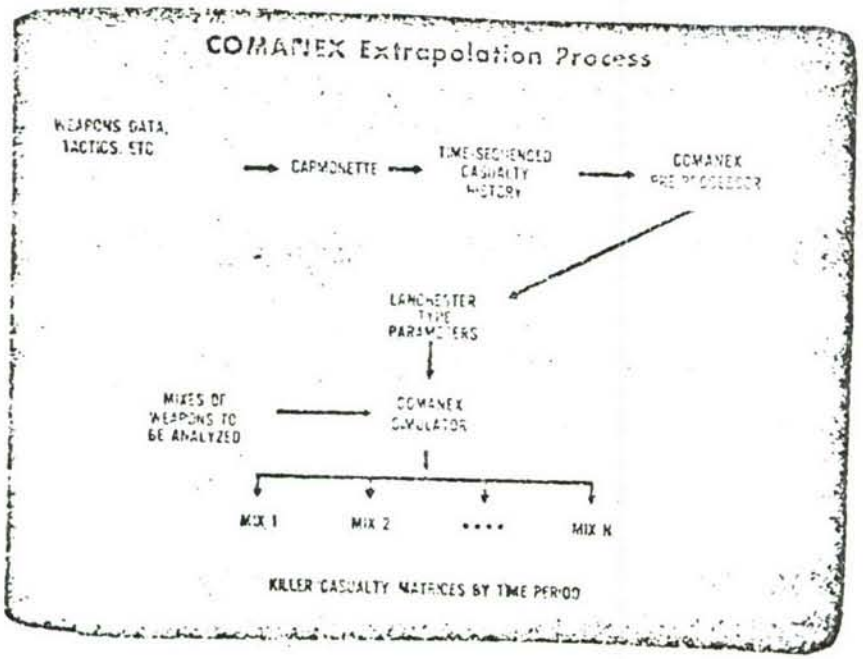


Figure 3-1

We mentioned earlier that COMANEX is based on certain extensions of classical Lanchester theory. To refresh your memories, Lanchester formulated two laws of combat in terms of differential equations—the so-called "Square Law" and the "Linear Law". The square law (direct fire) is applicable to those combat situations wherein the opposing forces are in full view of one another. Each unit is within firing range of every unit in the opposing force. The linear law (indirect fire) is applicable to those situations wherein none of the targets is visible. Fire is concentrated on a certain area known to be held by the enemy.

The first extension of the classical theory (Figure 3-2) is to introduce the concept of target acquisition probabilities. For P_b and P_r equal to zero the mathematical formulation of COMANEX reduces to the square law; as P_b and P_r approach 1 the formulation reduces to the linear law. Thus, the formulation covers combat situations intermediate between the two extremes of total target visibility and total invisibility.

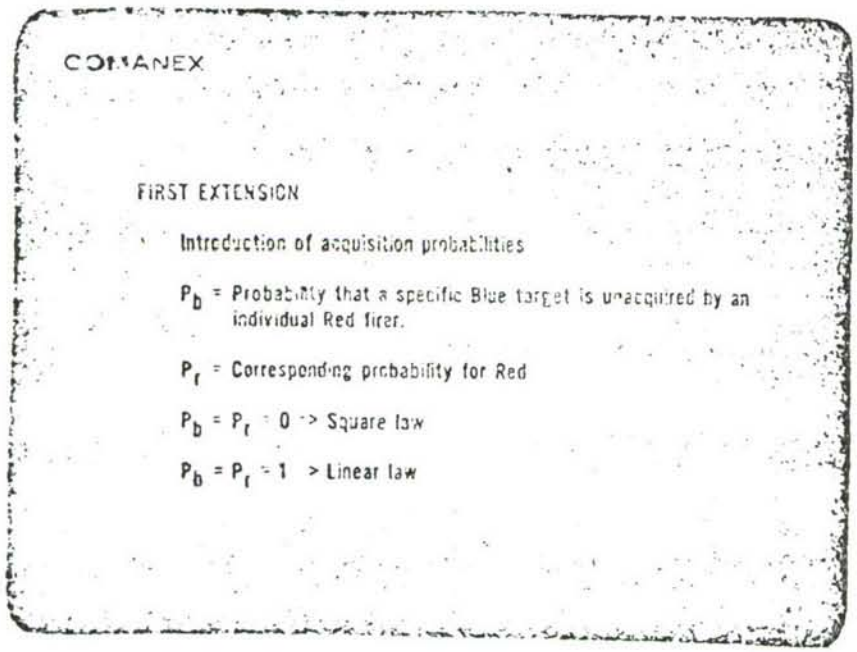


Figure 3-2

The second extension of the theory shown in Figure 3-3 is to introduce the concept of target priorities. Until now we have been talking about "homogeneous" forces—only one type weapon on each side; say tanks against tanks. When two or more types of weapons are involved, a unit is assumed to fire on an acquired target only if it has not acquired any higher priority targets. Target priorities for each weapon type are

input to the model in the form of firer/target preference matrices. We shall return to this point later.

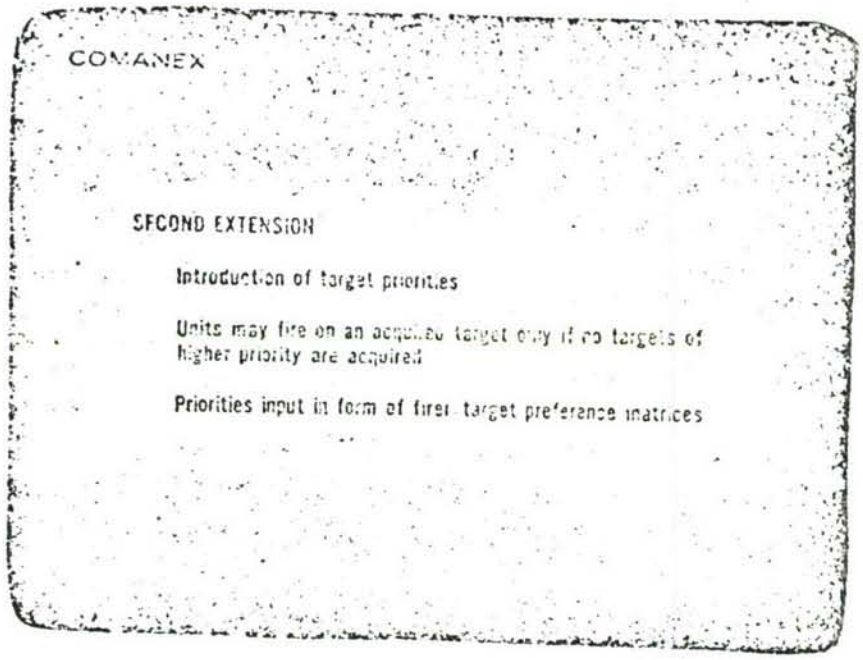


Figure 3-3

Figure 3-4 shows a comparison of the interpretations to be attached to the major parameters involved in each of the formulations. The parameters are usually referred to as attrition coefficients. We have defined them here only for Blue firers; similar expressions apply to Red firers.

The parameters b_{ij} (and r_{ji}) for all firer/target combinations in the battle form the basis upon which COMANEX is constructed. Knowing the values of the parameters, the acquisition probabilities and the numbers of surviving weapons at any given time, the expected casualty rates for each weapon type in the battle can be calculated. The total expected casualty rate, labelled C, is defined as the sum of all the individual rates. Using probabilistic considerations it can be shown that the time between casualties is exponentially distributed with parameter C. (1/C is the mean time between casualties.) Given that a casualty has occurred we can determine the probability that the casualty is of a certain type. Given the casualty type we can determine the probability that the killer is of a certain type.

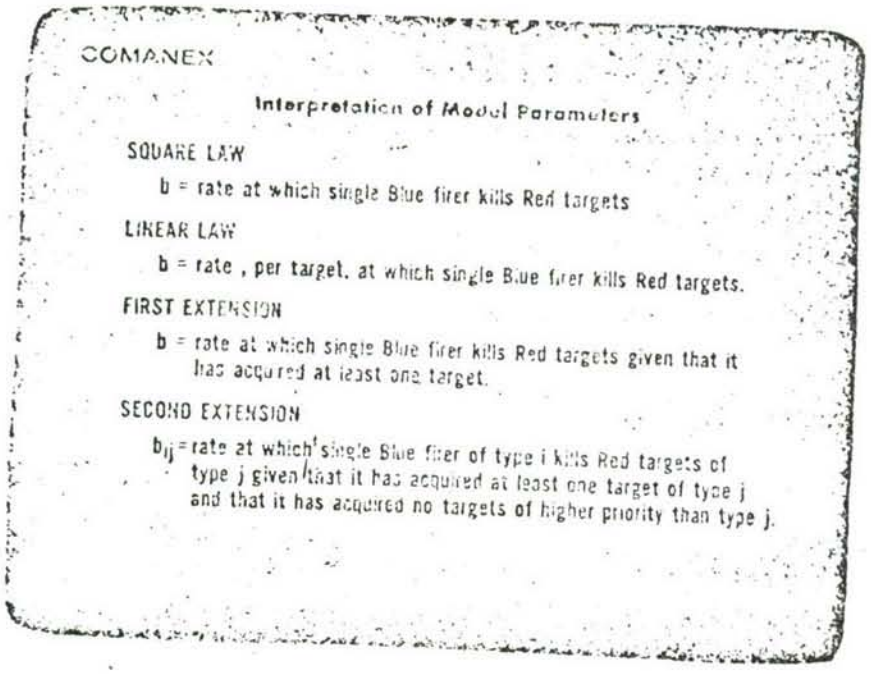


Figure 3-4

We are now in a position to discuss the processing logic employed in the COMANEX simulator (Figure 3-5). The flow diagram shown here is a bit over-simplified in that we have assumed the values of the parameters to remain constant throughout the battle. Actually, in practice, the battle is divided into a series of discrete time intervals each of which may have a different set of parameter values. The principle, however, remains the same.

We start out with the initial numbers of weapons on each side and calculate the expected casualty rate C. We draw an exponentially distributed (with parameter C) random number to determine the time of the first casualty. We then draw a uniformly distributed (0-1) random number to determine the casualty type, another uniformly distributed random number to determine the killer type. After removing the casualty weapon from the battle a new value of C is calculated on the basis of the number of surviving weapons. The process is repeated until the battle is over. The battle may be replicated as many times as desired. Typically, we have been performing 30 replications to determine expected battle results. The battle may be terminated at a pre-specified time or when either side has suffered a pre-specified fraction of casualties—weapons and/or personnel. The output is in the form of the killer/casualty matrices discussed previously.

COMANEX

Simulator

Given values of parameters r_{ji}, b_{ij}, P_r, P_b:

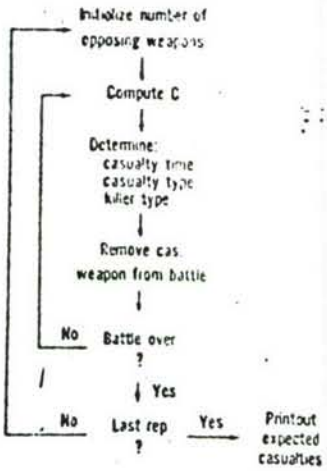


Figure 3-5

As we mentioned at the outset, the values of the model parameters are furnished by the COMANEX pre-processor (Figure 3-6). These values are calculated using the statistical principle of "maximum likelihood." We will not discuss the calculation procedure here as the mathematics is rather involved. Suffice it to say that a unique set of values is obtained that is "most likely" to have produced the results of the CARMONETTE replications of the original force mix. Conceptually, the procedure is analagous to fitting a curve to a set of observed data points by the method of least squares, although the actual mechanics are quite different.

The pre-processor inputs are as shown in Figure 3-6. For each CARMONETTE replication of the battle a casualty history table is extracted recording the casualty time, the casualty type, and the killer type. The dashed lines indicate the separation of each battle replication into a set of time intervals for which different sets of parameter values are to be calculated.

COMANEX permits different firer types to have different sets of target priorities. The priorities must be specified and input to the pre-processor for each of the designated time periods. The rows of the matrices, reading from left to right, list, in descending order of priority, the target types for a particular firer type. For example, in this

illustration, Red type 2 units are the highest priority targets for Blue type 2 firers; Red type 1 targets have second priority; Red type 5, third.

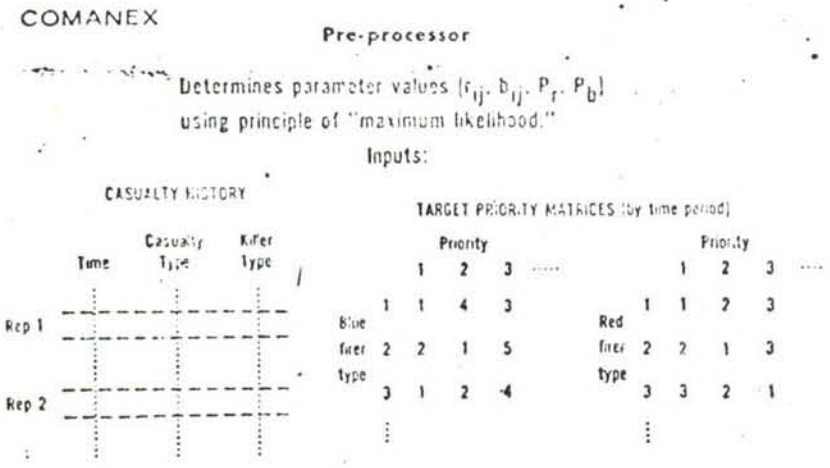


Figure 3-6

This completes our general description of COMANEX.

We would now like to show you the results of a typical case comparing CARMONETTE results to those obtained from COMANEX.

The force mix to be analyzed is presented in Figure 3-7. Red is attacking, Blue defending. The numbers on the left serve as identifiers for the particular weapon types. The numbers in parentheses indicate the initial numbers of individual weapons in the battle. Using this force mix, seven replications of the battle were performed by CARMONETTE. The casualty history data were input to the COMANEX pre-processor which output a set of Lanchester-type parameters for each of four consecutive 5-minute time intervals. The parameters were input to the COMANEX simulator which then performed 30 replications of the battle. To give you an idea of the relative computer running times involved: CARMONETTE

required roughly 45 minutes to perform the seven replications; it took approximately 30 seconds to extract the casualty history table, 70 seconds for the pre-processor to calculate the model parameters, and 40 seconds for the simulator to perform the 30 battle replications.

COMANEX Test Mix

BLUE FORCE	RED FORCE
1. TANK (5)	1. TANK (18)
2. APC (6)	2. APC (27)
3. DRAGON (6)	3. BRDM (3)
4. TOW (4)	4. SAGGER (2)
5. HELICOPTER (2)	5. 76mm RR (2)
6. INFANTRYMEN (54)	6. INF. (102)
7. 81mm MORTAR (3)	7. 152mm HOW (15)
8. 4.2" HOWITZER (4)	8. 23mm AD (4)
9. 155mm HOW. (8)	9. 57mm AD (2)
10. 8" HOW. (4)	10. STRELA (2)
11. LAW (6)	11. 120mm MOR (4)
	12. RPG (27)
	13. 14.5mm AD (2)

Figure 3-7

Figure 3-8 shows the comparison of results, in terms of expected Blue casualties at the end of 10 minutes of battle. The numbers listed vertically identify the Red firer types; those listed horizontally, the Blue target types. For example, the CARMONETTE matrix indicates that 0.3 TOWs were killed by tanks, 1.2 by APCs, for a total of 1.5. The corresponding numbers determined from COMANEX are, respectively, 0.2, 1.1, and 1.3.

Figure 3-9 shows the comparison of expected Blue casualties at the end of 20 minutes of battle. The last two figures, 3-10 and 3-11, provide a similar comparison for Red casualties.

The comparisons demonstrate rather conclusively that COMANEX can accurately reproduce CARMONETTE battle results. The next step, of course, is to determine how accurately COMANEX can predict CARMONETTE results. That's the problem we are working on at the moment.

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COMANEX

Blue Casualties (10 min)

CARMONETTE
Blue Target Types

Red Fixer Types	1	2	3	4	5	6	7	8
1	0.5		0.1	0.3		0.5		
2	1.0			1.2				
3								
4								
5								
6								
7	0.1					6.0		
8	0.1							
9								
10								
11						0.8		
Σ	1.7		0.1	1.5		7.3		

COMANEX
Blue Target Types

Red Fixer Types	1	2	3	4	5	6	7	8
1	0.5		0.3	0.2		0.7		
2	1.0			1.1				
3								
4								
5								
6								
7	0.1					5.9		
8	0.1							
9								
10								
11						0.9		
Σ	1.7		0.3	1.3		7.5		

Figure 3-8

COMANEX

Blue Casualties (20 min)

CARMONETTE
Blue Target Types

Red Fixer Types	1	2	3	4	5	6	7	8
1	1.6		0.6	0.4		1.8		
2	1.5		1.3	1.3				
3								
4	1.0		0.2	0.6				
5								
6								
7	0.1					15.2		
8	0.1			0.1				
9								
10								
11						1.4		
Σ	4.3		2.1	2.4		18.4		

COMANEX
Blue Target Types

Red Fixer Types	1	2	3	4	5	6	7	8
1	1.3		0.8	0.4		2.2		
2	1.7		1.1	1.2				
3								
4	0.9		0.2	0.5				
5								
6								
7	0.1					14.4		
8	0.1			0.1				
9								
10								
11						1.5		
Σ	4.1		2.1	2.2		18.1		

Figure 3-9

COMANEX

Red Casualties (10 min)

CARMONETTE
Red Target Types

Blue Fixer Types	1	2	3	4	5	6	7	8
1	0.6	0.8						
2								
3								
4	2.4	7.2	0.4					1.5
5	0.4	1.0						0.6
6								
7						0.1		
8						0.5		
9		0.1		0.1		2.0		
10						0.9		
11								
Σ	3.4	9.1	0.4	0.1		3.5		2.1

COMANEX
Red Target Types

Blue Fixer Types	1	2	3	4	5	6	7	8
1	0.5	0.8						
2								
3								
4	2.4	7.2	0.5					1.3
5	0.6	1.0						0.7
6								
7						0.1		
8						0.4		
9		0.1		0.1		2.2		
10						0.9		
11								
Σ	3.5	9.1	0.5	0.1		3.6		2.0

Figure 3-10

COMANEX

Red Casualties (20 min)

CARMONETTE
Red Target Types

Blue Fixer Types	1	2	3	4	5	6	7	8
1	3.5	3.7	0.3	0.3		1.1		
2								
3	0.1	1.6						
4	2.7	7.7	1.0	0.4				1.8
5	1.4	2.2	0.1					2.0
6								
7						0.8		
8						2.5		
9		0.1		0.1		8.1		
10						1.9		
11								
Σ	7.7	15.3	1.4	0.8		14.4		3.8

COMANEX
Red Target Types

Blue Fixer Types	1	2	3	4	5	6	7	8
1	3.0	4.0	0.1	0.1		1.4		
2								
3	0.1	1.5						
4	2.5	7.6	1.3	0.6				1.5
5	1.3	1.9	0.1					1.8
6								
7						1.0		
8						2.1		
9		0.1		0.1		8.7		
10						1.8		
11								
Σ	6.9	15.1	1.5	0.8		15.0		3.3

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Figure 3-11

4

DIVISION BATTLE MODEL (DBM)

The DBM is a manually operated, computer assisted war game designed to support studies of the performance of weapons, organization, and tactics employed by a division-size force engaged in combat in a conventional or nuclear environment against an appropriate force (Figure 4-1).

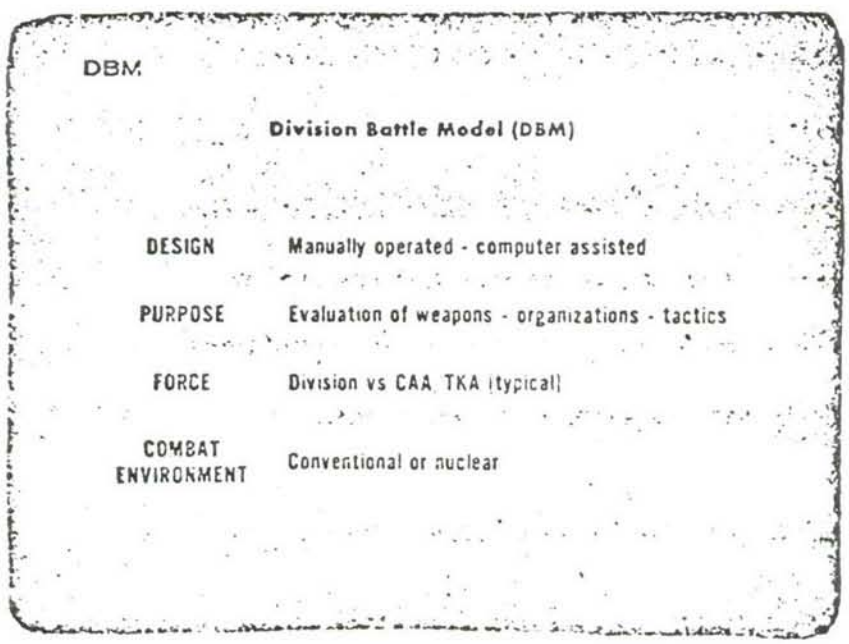


Figure 4-1

DBM is played on a map with a scale falling within the 1:25,000 to 1:50,000 range. This provides sufficient detail to support the levels of unit, time, and space resolution employed. The normal level of resolution for maneuver units within a division-size force is the company;

however, for opposing CAA or TKA, the battalion may be more satisfactory. In either case detailed records are maintained regarding the inventory of men and weapons assigned to these units and battle assessments are based on current strengths. The battery or battalion is the normal level of resolution for artillery units, and the company or squadron for air units. Assessment procedures are based on salvos fired or sorties flown by these units. Time is measured to the nearest 5 minutes and space to the nearest 100-meter square.

The game may be played in an open, semi-closed, or closed mode, depending on the degree to which information affecting the opposing player decision is considered important to game objectives. The game progresses at an accelerated pace in open play, since a closed or semi-closed mode requires time consuming message center and map-posting activities to keep the restricted player sufficiently advised of the situation to maintain the continuity of the game. In closed play, 2 to 4 hours of combat can be processed per working day with a team consisting of one director, seven gamers, and three support personnel. In open play the rate of play can be accelerated to 4 to 6 hours of combat per working day with a team comprised of one director, three gamers, and two support personnel (Figure 4-2).

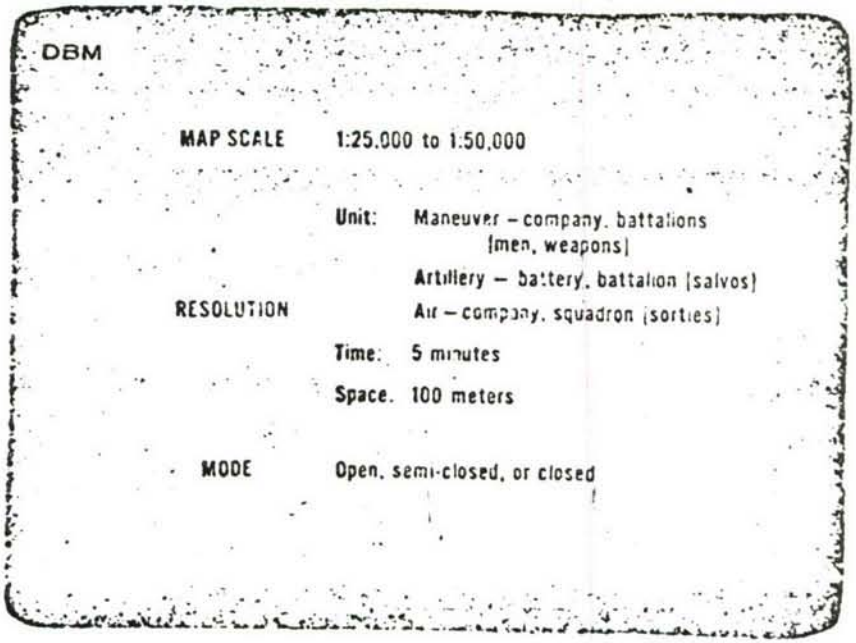


Figure 4-2

The manual operations of DBM are concerned primarily with decision making and the determination and time sequencing of events on the battlefield. The computer programmed portion focuses on the determination of battle losses, tabulation and reporting of battle results, and the updating of stored information (Figure 4-3).



Figure 4-3

Figure 4-4 depicts the activities conducted manually, and by the computer, in the DBM. The game scenario sets the stage for the initial sets of player orders to subordinate units and for requests to higher headquarters for support. These player actions result in unit movements and activities which are recorded on the game map and translated into time-sequenced events by the controller in accordance with applicable game rules. Reports of these events are prepared for delivery to players at the appropriate times. If the event is one which falls within the purview of a computer submodel, for example, an air strike or the joining of close combat between two or more opposed units, the controller also prepares a line entry on the appropriate input sheet for computer assessment following the completion of manual operations. Upon the receipt of unit reports, players may take such action as deemed appropriate, modifying existing orders, issuing additional orders, requesting additional support, etc. These orders and requests are processed by control, as previously described.

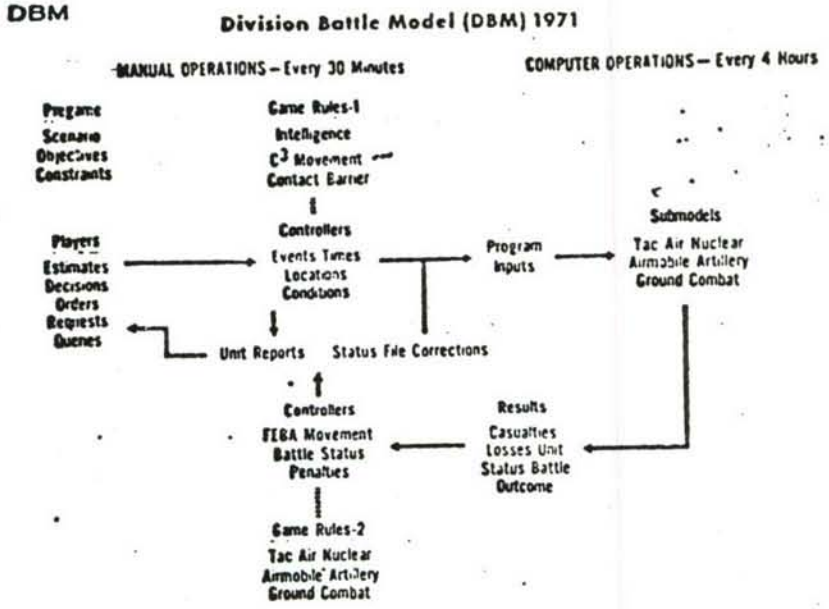


Figure 4-4

Manual operations normally continue in this manner for 4 hours of play (game time), or until, in the opinion of the senior controller, a critical event has occurred. At this point, manual operations are suspended and the computer inputs describing the various combat actions occurring during the manual cycle are processed.

The computerized portion of DBM employs a unit status file which lists the current inventory of personnel, weapons, and major items of equipment of each unit being gamed, and of a series of combat assessment routines which may be called and recalled in any sequence. Unit status files are adjusted following each assessment to reflect battle losses incurred. Thus, the results of an air strike delivered prior to a ground combat action may be assessed and the strength of the targeted units adjusted to reflect losses occurring before the ground combat action occurs. However, if the air strike occurred following the ground combat action, the calling sequence of the ground combat and air models would be reversed and losses sustained as a result of the strike would not be deducted until after the ground combat assessment was completed.

Following the computer run, a printout of the results is provided to the controllers. Included is a report of personnel casualties and losses of major items of equipment and weapons by cause, ammunition expenditure, and the current state of each unit as reflected in the updated unit status file.

The control team utilizes this information to make adjustments of the FEBA resulting from ground combat and to determine the battle status of engaged units. This information is also passed to the players in the form of unit reports. Adjustments to the unit status file reflecting receipt of supplies and/or replacements may also be made at this time. In this connection the computerized model has an automatic resupply/replacement routine which may be employed if desired.

Manual play is now resumed, following the sequence of operations previously described. This cyclic process is continued until game objectives are attained.

Now, a bit more detail on the DBM computerized-assessment routine. DBM offers an innovative approach to the assessment of ground combat. A small unit combat simulation, CARMONETTE, is employed to develop weapon system performance data which is then used in DBM ground combat assessments. The advantage of this approach over traditional methodology based on weapon firepower scores is that weapon and unit performance measures developed by CARMONETTE reflect variations in the combat environment, including the synergistic effects resulting from the employment of various combinations of weapons. The translation of CARMONETTE outputs into DBM assessments is accomplished by use of the COMANEX model, as earlier described.

Supporting fire delivered by artillery may be assessed either in the ground combat routine or in the separate artillery routine. The first option is normally employed if the targeted unit is engaged in ground combat while the fires are being delivered. The second option is used for fires delivered against targets not directly and immediately engaged in ground combat; e.g., reserve units, headquarters, counter-battery fires, interdiction and harassing fires, preparatory fires, etc. CARMONETTE output data are not required for operation of the DBM artillery routine.

The attack helicopter routine was originally developed to assess missions conducted by attack helicopters, however, these missions are now being processed in the ground combat routine. The attack helicopter routine is now used only in attack missions involving a significant penetration of the enemy force.

At the present time, high performance air (HPA) strikes can be assessed only in the DBM tac air routine, since CARMONETTE does not have an HPA capability and cannot therefore provide the data necessary for the DBM ground combat model. This situation will be corrected with the development of a CARMONETTE HPA routine this year, however, in the interim, HPA strikes against units engaged in ground combat (close air support missions) must be assessed by interrupting the ground combat model at the appropriate time, calling the tac air model to assess the air strike, then recalling the ground combat model to continue the basic assessment.

The DBM tac air routine is also employed to assess the air-to-air, air-to-ground, and ground-to-air actions involved in those air-interdiction, armed reconnaissance, and air defense missions ordered by player teams.

The DBM nuclear routine assesses casualties and materiel losses resulting from the successful delivery of nuclear warheads. The process of delivering the warhead is assessed in either the HPA or artillery routine depending on the delivery means. Residual effects of nuclear contamination are assessed manually.

The airmobile routine is employed to assess losses incurred by units being airlifted by airlift escorts and by defenders.

The man-machine relationship existing in DBM methodology is intended to provide flexible and realistic responses to changing battlefield conditions and an efficient means of assessing battlefield interaction and recording results. Accordingly, estimates and decisions are made by appropriately-experienced men; while calculations, record keeping, and reporting are primarily computer functions. The interfacing of CARMONETTE with DBM avoids the long-standing shortcomings of firepower scores, making it possible to relate weapon and unit characteristics to the combat environment to produce credible weapon and unit effectiveness measures at the division level.

5

SIMULATION MODEL FOR EVALUATING SYSTEMS IN PROLONGED INTENSIVE COMBAT (EPIC)

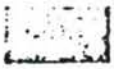
The EPIC simulation is a computerized deterministic model designed to evaluate the long-term performance of systems within an operational context. The model was developed as part of the ADAFSS Force Mix study at Research Analysis Corporation. A brief review of the requirements guiding its development should help to convey a general understanding of the design features and potential applications of EPIC.

The model was required to produce the daily and cumulative expected results that might be achieved by different numbers, types, and mixes of attack helicopters over extended periods of combat. Another requirement was to represent the hard facts of operational reality that are generally ignored in high resolution simulations, which focus on a brief fire exchange within a very narrow context. These hard facts include such considerations as limitations on flight hours per day, maintenance time required as a function of flight time, fleet attrition over extended periods, mission availability, aircraft reliability, and repair times for damaged aircraft. Missions had to be distributed throughout successive 24-hour periods to reflect demand as a function of weather and the level of combat activity and aircraft had to be assigned to these missions on the basis of availability and in accordance with the underlying principles that dictate assignment in actual operations.

To accommodate the many operational aspects of interest, EPIC uses a hierarchy of time resolutions as shown in Figure 5-1. The basic time interval is selected to suit the problem at hand. In past applications of the model time steps of 1 minute, 5 minutes and 15 minutes have been used, depending on the maximum resolution required. Use of the hierarchy of time resolutions permits the model to execute very rapidly.

EPIC uses a dynamic mission assignment logic. This logic makes use of feedback loops that control the expenditure of available resources in such a way as to maximize the value of a predefined effectiveness measure. In effect, this logic simulates the mission assignment decision processes of experienced operational personnel.

Figure 5-2 gives a summary of EPIC inputs. The final input items, a table of mission descriptions, is generally produced as the output of high-resolution simulations.



EPIC MODEL

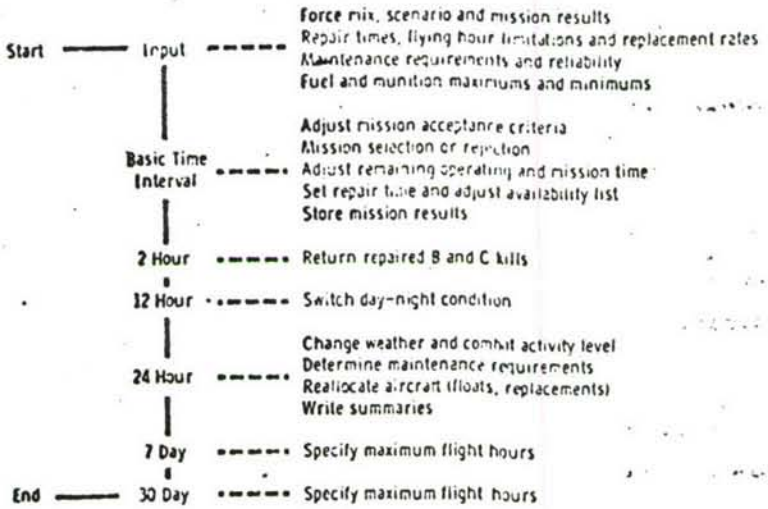
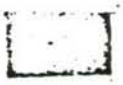


Figure 5-1



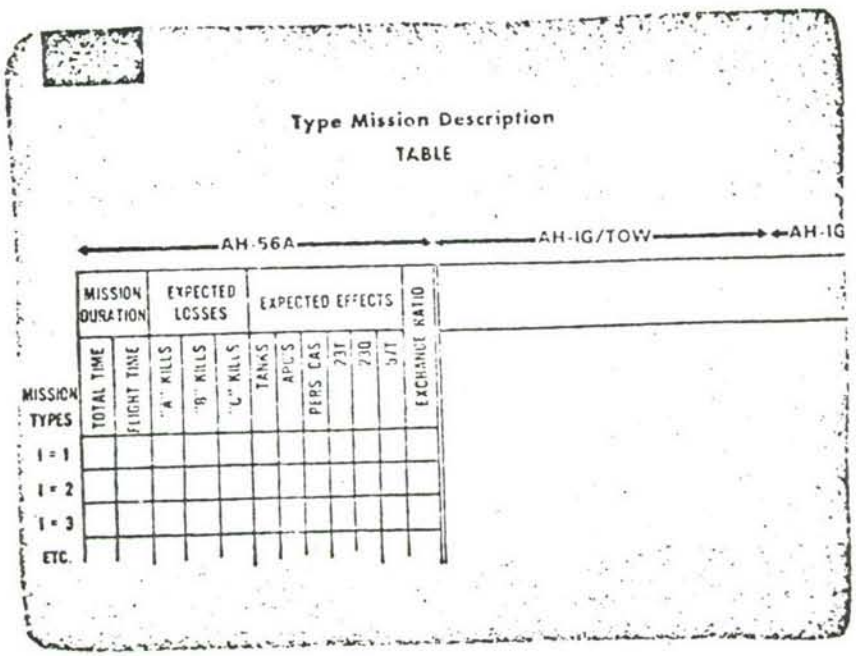
INPUTS

1. Size of force
2. Schedule of type activity days
3. Schedule of weather conditions
4. Schedule of tank replacements
5. Criteria for initial allocation of tank force
6. Down times associated with recoverable M and F kills
7. Limitations on equipment and/or crew operating hours/day, week, month
8. Maintenance down time/operating hour
9. Reliability
10. Mission description table

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Figure 5-2

Figure 5-3 shows typical mission results entries input to EPIC for evaluating attack helicopter performance. The mission types here reflect the nature of the target, its posture, visibility and weather. For example, mission type 1 might indicate a reinforced tank company, attacking in the daytime, under good weather conditions. For each mission type the associated times, expected friendly losses, and expected target effects are input to EPIC.



Type Mission Description

TABLE

AH-56A → AH-IG/TOW → AH-IG

MISSION TYPES	MISSION DURATION		EXPECTED LOSSES			EXPECTED EFFECTS						EXCHANGE RATIO
	TOTAL TIME	FLIGHT TIME	"A" KILLS	"B" KILLS	"C" KILLS	TANKS	APCS	PERS CAS	23F	230	57T	
I = 1												
I = 2												
I = 3												
ETC.												

Figure 5-3

Typical outputs produced by the EPIC model are shown in Figure 5-4. The output processor of the model prepares both periodic and cumulative reports. The time resolution of these reports is a matter of user choice. When longer periods of sustained combat—say, from 30 to 90 days—are simulated on the model, experience has shown that 24-hour periodic and cumulative output summaries are most convenient. When the model was used in support of the Advanced Attack Helicopter Task Force, scenarios of 3 days and 14 days were played. It was found that 2-hour reports provided a suitable level of detail for the 3-day games and that 12-hour reporting was most convenient for the 14-day games.

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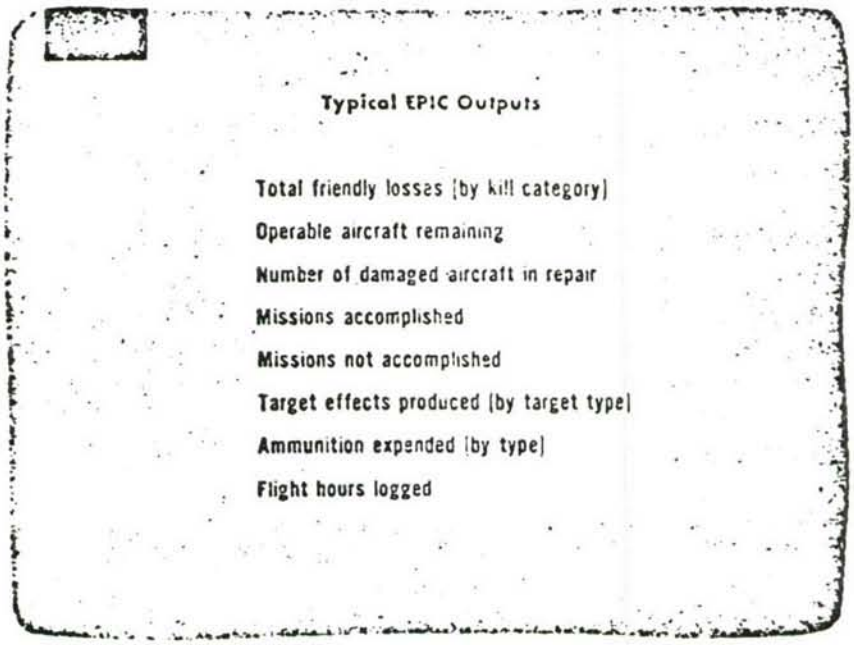

Typical EPIC Outputs
Total friendly losses (by kill category)
Operable aircraft remaining
Number of damaged aircraft in repair
Missions accomplished
Missions not accomplished
Target effects produced (by target type)
Ammunition expended (by type)
Flight hours logged

Figure 5-4

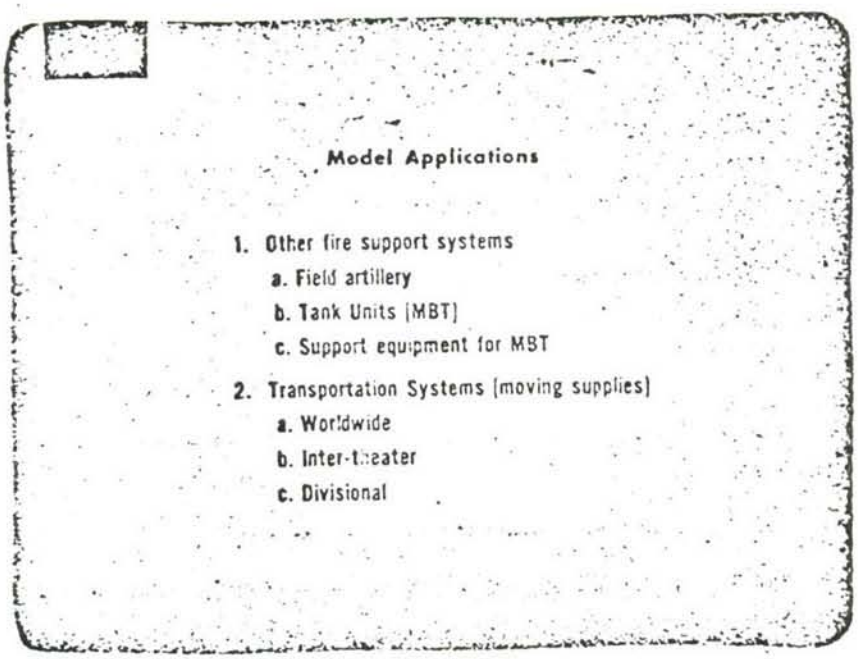


Figure 5-6

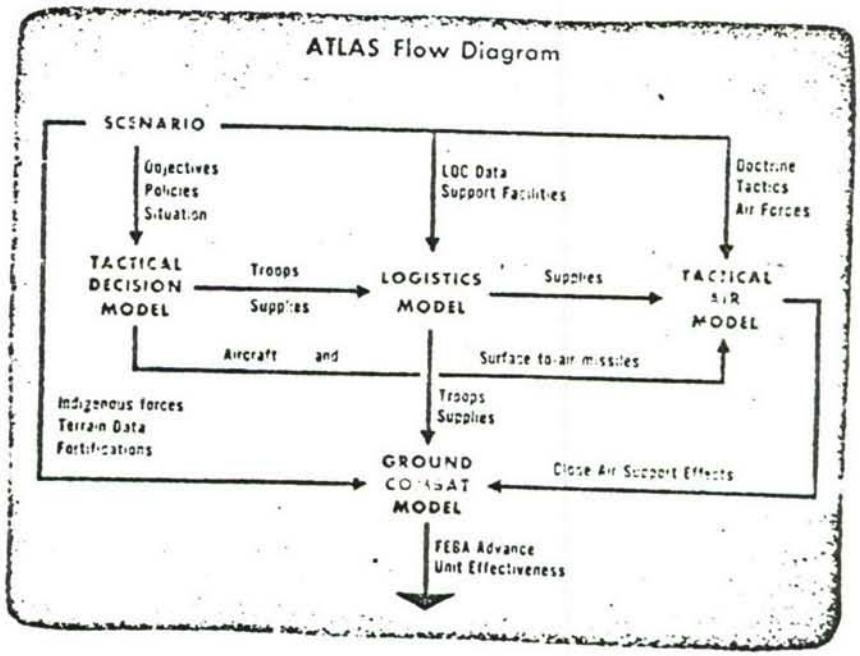
EPIC is an expected value model and, as such, produces its solution in a single run. This means it is an economical model to operate. EPIC results have been found to be consistent with the mean results of multiple Monte Carlo replications.

6

ATLAS - A THEATER LEVEL COMBAT SIMULATION

ATLAS is a computerized theater level combat simulation consisting primarily of four models: the Ground Combat Model, the Tactical Air Model, the Logistics Model, and the Tactical Decision Model.

Figure 6-1 shows in a general flow diagram the composition of ATLAS. A game scenario which states the specific objectives, the constraining policies to be followed, and the combat forces available, essentially guides the simulation from the start. From this scenario and the developing tactical situation comes information which triggers the tactical decision model into sending troops, supplies, and equipment to the other models. These models then interact in a tactical sense and thus develop the combat situation.



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Figure 6-1

The simulation regards the tactical battlefield as being divided into non-interacting battle areas called sectors, shown in Figure 6-2.

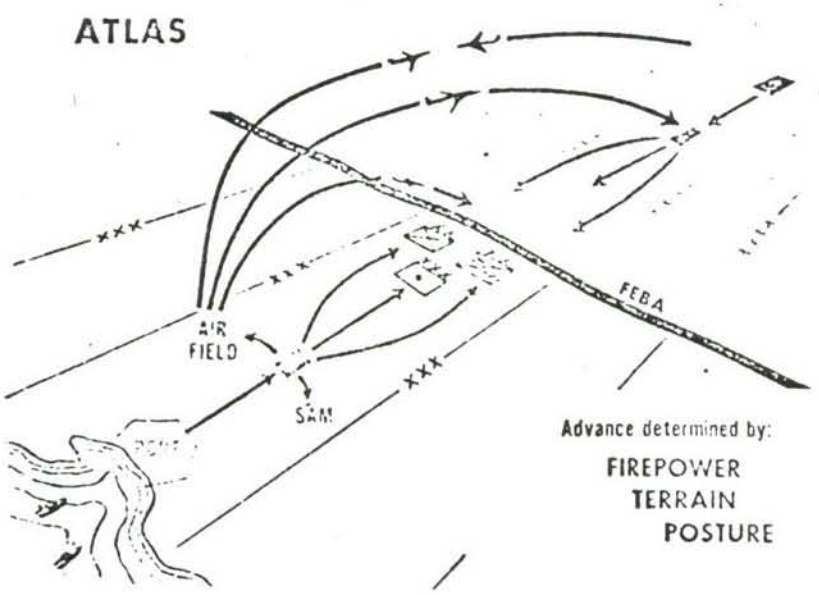


Figure 6-2

In general, the smallest discrete combat unit simulated in any given sector is a combat division. Since the ground combat model is designed to determine unit advance, each sector is further divided into segments so that trafficability within each segment may be considered constant. Terrain and natural or manmade barriers affect military movement, so six types of terrain-barrier combinations are simulated in the model.

Each battle sector also has a logistics system, a one-dimensional supply system extending from theater ports or central staging areas to the most forward supply area near the combat zone. Intermediate supply centers or supply nodes are simulated to service airbases and other rearward elements.

To complete the view of the ATLAS battlefield, we show tactical aircraft activities: interdiction, air-to-air engagements, and close air support.

Tying these three models together so that the simulation may proceed day-by-day with no interruptions is the function of the tactical decision model, which we will describe later.

GROUND COMBAT MODEL

The functions of the ground combat model are shown in Figure 6-3. In attempting to calculate the daily advance of the attacking force, this model examines the forces assigned to combat on each side and determines their present level of combat effectiveness in accordance with a loss of personnel or supplies and equipment.

FUNCTIONS OF GROUND COMBAT MODEL

COMPUTES	AS A FUNCTION OF
RATES OF ADVANCE	Force Ratio Terrain Unit Type
CASUALTIES PER DAY	Engagement Type Unit Type
UNIT EFFECTIVENESS	Unit Activity % Casualties

Figure 6-3

The measure of combat effectiveness used in the model is called ICE (Index of Combat Effectiveness), based on the relative firepower of units.

In determining how effective a combat unit is on a given day, we have assumed that its effectiveness can be measured as a function of the percent casualties to the unit, the level of the unit's supplies and equipment, and the particular activity of the unit—attacking or defending. To determine at what point a combat unit becomes ineffective is a difficult procedure. However, the effects of casualties must be taken into account and this is accomplished by the effectiveness curves shown in Figure 6-4. These curves indicate the percent degradation of unit effectiveness as a function of casualties received when attacking or defending. Note that the effect of a given casualty level is greater on an attacking unit than on a defending unit. This is because an attack normally requires rapid movement, good coordination, and higher organizational integrity.

Other curves are available for degrading effectiveness as a function of supply level. The effectiveness value finally used is the minimum of the value due to casualties or the value due to lack of supplies.

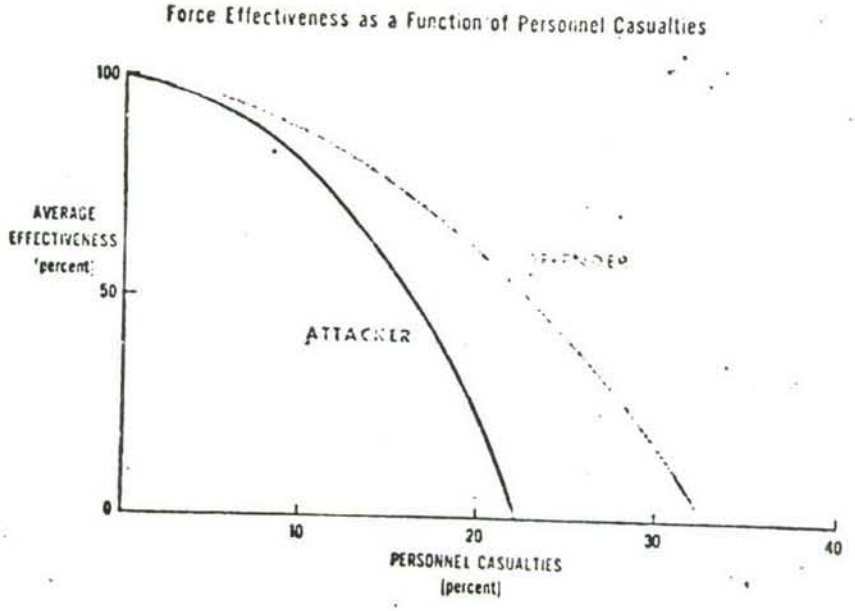


Figure 6-4

The modified combat effectiveness values when viewed as a ratio of values (attacker to defender) are used to determine the daily rate of advance, as shown in Figure 6-5. This force ratio combined with the terrain, the type units in the attacking force, and the type combat engagement determine the distance advanced for that day's action. Shown are the rates of advance for an armor unit attacking in terrain type A, no barrier, against various defense postures.

Also shown are the seven type defense postures simulated in the model—from fortified position thru hasty defense to disorganized retreat.

The casualty rate curves used in the model are shown in Figure 6-6. This set of casualty data is a function of type engagement and force ratio. This completes discussion of the ground combat model.

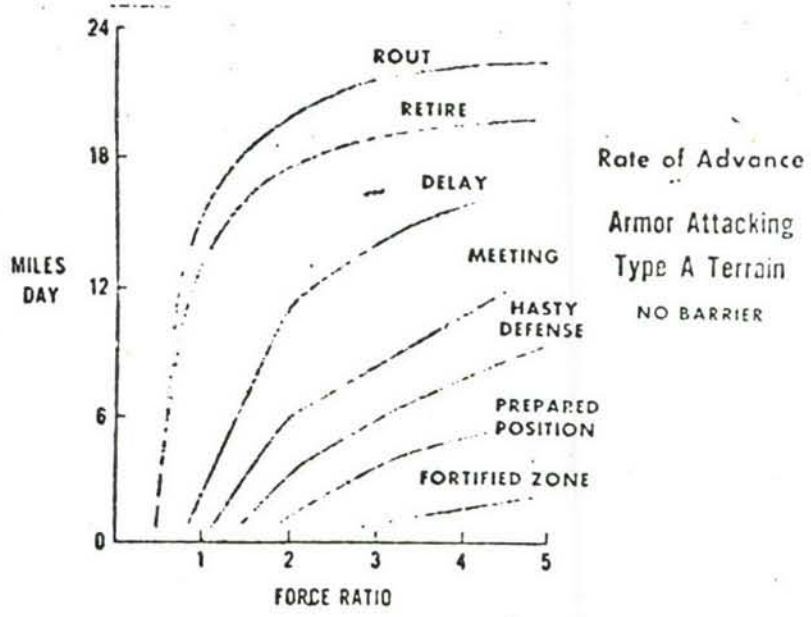


Figure 6-5

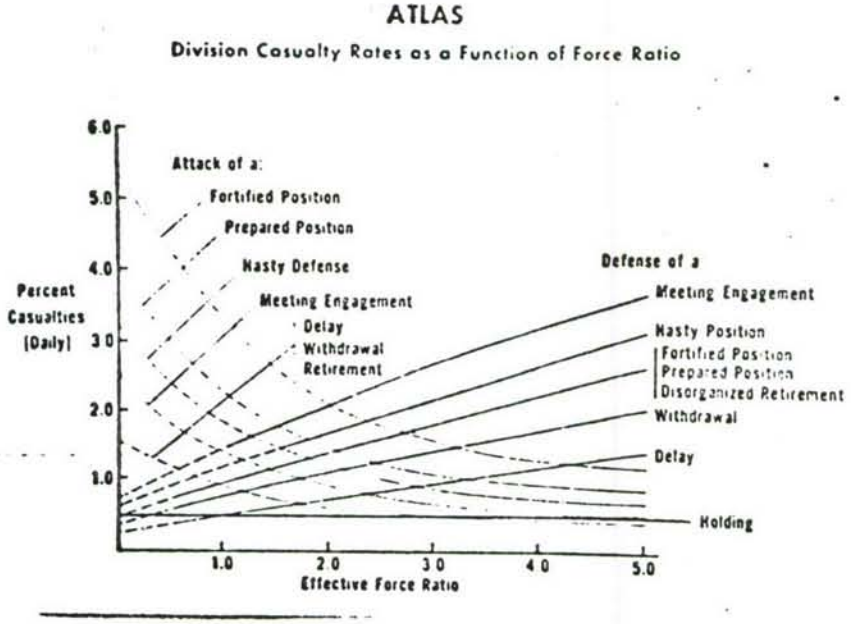
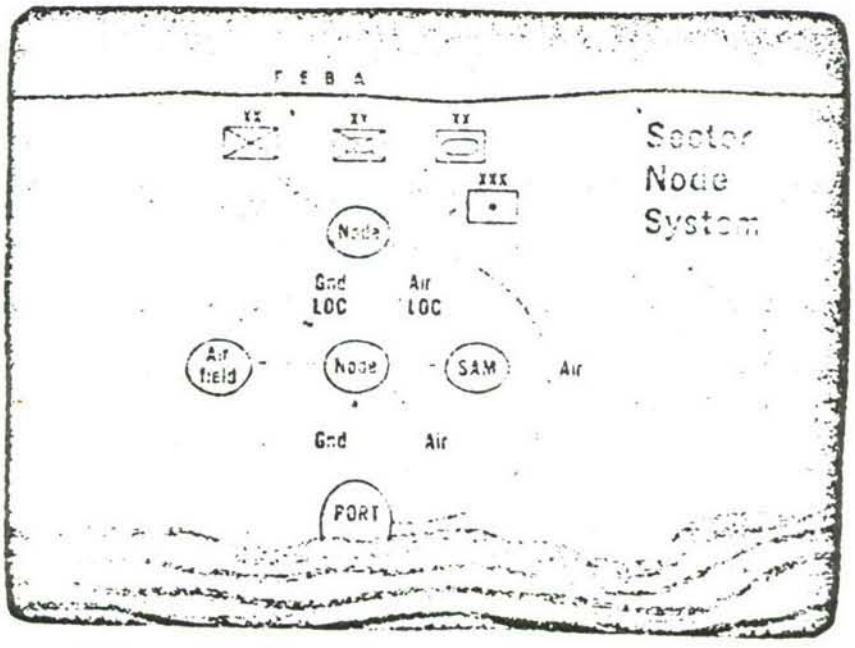


Figure 6-6

LOGISTICS MODEL

In order that ATLAS be capable of realistically assessing the outcome of deploying forces rapidly to meet a given threat, a model of the theater logistics capability is required. A model of this nature should simulate such things as the movement of supplies to the deployed combat units, the interdiction of supplies being forwarded, the movement of new units through the theater to the combat zone, and the stockpiling of supplies within the theater, if desired. A basic premise of the model is that the resupply of deployed units takes priority over the deployment of new units, with the building of stockpiles taking third priority.

Within each battle sector, the network of LOCs, both rail and road, are represented by a single series of supply nodes. These supply nodes (see Figure 6-7) are located for each side approximately 1 day's overland journey apart. Each node is described by certain characteristics that indicate the maximum daily output by ground means, lift helicopters, or fixed wing transport aircraft. If a specific node is required to stock a certain level of supplies, this is also indicated. Nodes which simulate ports or large airbases generally are the receiving points for direct delivery of troops, supplies, and equipment into the theater. The operational capabilities of these nodes are scenario dependent and are specified in the input data.



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Figure 6-7

For each combat sector the node immediately behind the FEBA is designated the forward supply point, and is responsible for resupplying all the combat troops in that sector. For the first day of combat, the supply node which is to be the forward node is specified in the input data. Thereafter, the movement of the FEBA is examined to discover whether the previous day's forward supply node has been overrun, or if it can now be moved to a more forward node.

The logic that simulates the flow of supplies is the same for each sector and deals first with the forward node. A demand from the ground combat units, which varies with the number and type of demanding unit as well as its combat posture, is created and sent to the forward supply node. If this node cannot meet the demand, the next most rearward node attempts to meet it. If this node also fails, supplies may be forwarded by air from a more rearward node if the capability is available.

When the daily movement of supplies has been completed all remaining ground and airlift capacities are used to move fresh troops and equipment to the combat zone.

The logic of this model was designed so that for stable combat conditions and adequate logistic support, supplies should flow smoothly into the forward supply node and hence to the consuming units. However, if the movement capabilities are low, or the enemy interdiction effort is heavy, the combat effectiveness of active units may be degraded and the total number of combat missions that could be flown from any one airbase may be restricted.

The ground model handles the daily combat actions (and the subsequent FEBA advance) and the logistics model attempts to keep supplies moving forward to insure maximum combat effectiveness.

TACTICAL AIR MODEL

The tactical air model accounts for mission assessments of the type shown in Figure 6-8. Daily operation of the air model depends on a tactical air controller, simulated within the decision model, to assign combat aircraft to each sector. Aircraft are assigned to sectors on the basis of the tactical environment, the airbase capability and the aircraft availability.

Once aircraft are assigned to sectors, the air model makes assignments to specific airbases within the sector for a home base location and logistical support. The home base location is necessary as a basis for evaluating the combat radius of the aircraft. A combat radius determines the maximum depth to which missile sites, airbases, and supply nodes may be interdicted. All distances are calculated from the node that supplies the home base to the nodes associated with the target elements.

Target elements such as missile sites and air bases are specific missions in the general air superiority role. The logic of the air model assumes that all active airbases and missile sites within range of the combat aircraft are vulnerable to attack.

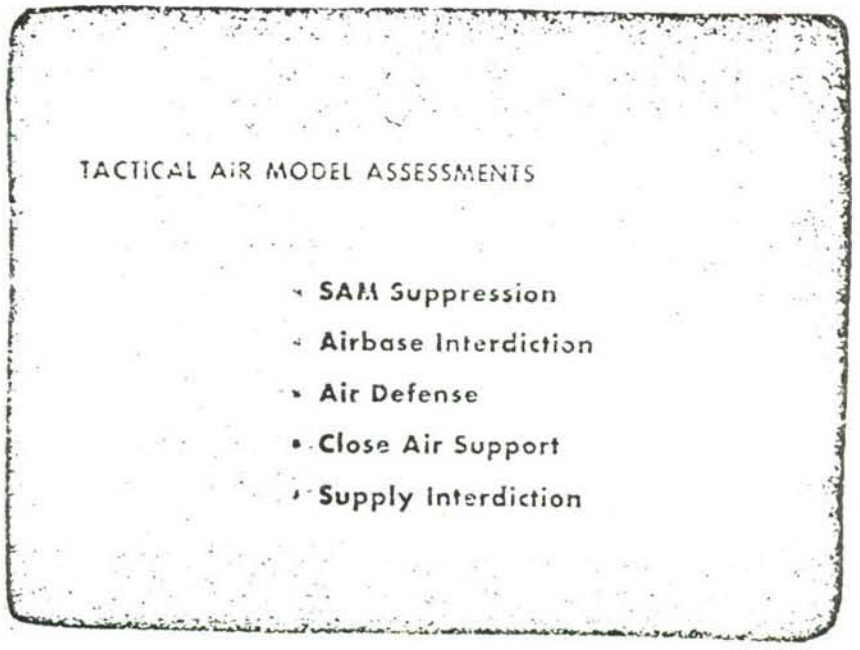


Figure 6-8

Airbase Interdiction

When attacking enemy airbases the number of aircraft assigned to attack each airbase is a function of the nearness of the airbase to the FEBA and the ability of the airbase to handle large numbers of aircraft sorties per day. Assessments are directed to airbase facilities, on-hand supplies, and the parked aircraft. Thus, whenever an airbase is attacked, the capability of that airbase to sustain a given number of sorties per day is a characteristic that is degraded.

SAM Suppression

A second major target element is the surface-to-air missile (SAM) unit. The number of aircraft assigned to attack each SAM site is in proportion to the number of fire units at the site. The number of fire units lost to aircraft attack is a function of the number of fire units

available at the site, the effectiveness of the aircraft attacking the missiles, and the total number of aircraft attacking the site.

In computing the aircraft lost to missile fire, two single salvo (or single shot) kill probabilities are used. All kill probabilities are based on the type missile system deployed and its firing doctrine which may be one, two, or more, missiles per salvo. One kill value is applied against aircraft whose mission is to attack the missile site, and another value is applied to all other missions. Since close air support aircraft generally operate at a lower altitude, they receive the lower value missile assessment and thereby become more vulnerable to air defense artillery weapons in the area.

Air Defense Losses

The loss of aircraft to these air defense weapons in the forward combat area is determined by an overall attrition constant per sector. The attrition constant is a weighted average of the effectiveness of air defense weapons organic to combat divisions and supporting elements within each sector. Once the attrition effect is determined for each division, the ratio of air defense effectiveness to division ICE is formed and kept constant. As the division ICE is reduced by close air support or other battle actions, the air defense attrition constant is similarly reduced.

Close Air Support

The close air support effects assessed in the model are determined in a very straightforward manner. Various studies have indicated what a standard or near optimum munition loading would be for aircraft on a close air support mission. Using this standard loading and computing the lethal area of effects for the munitions, an equivalent ICE for a close air support aircraft can be calculated. This value multiplied by the total aircraft assigned to close air support yields the ICE that is to be added to the combat unit's ICE and then assessed in the ground model for that day's action. The ICE for close air support is computed on a daily basis to account for loss of aircraft and/or changes in close air support tactics.

Supply Interdiction

The last mission type to be assessed is the supply point interdiction operation. As before the aircraft will attack supply nodes in depth out to the combat range of the aircraft. The number of aircraft assigned to attack each node is in proportion to the size of the node as determined by its output capacity, its on-hand supplies, and its air resupply capability.

LOCATION

To have the air model operate on a 24-hour cycle from day to day ut additional mission type orders requires a routine to assign air- ; to tactical missions each day. This is done by a set of mission gnment curves as shown in Figure 6-9. The number of aircraft assigned ach mission is determined by the relative strength of air power per or. As one side achieves air superiority, more and more aircraft assigned to close air support and interdiction missions. The curves entirely arbitrary. Any set of such curves may be used.

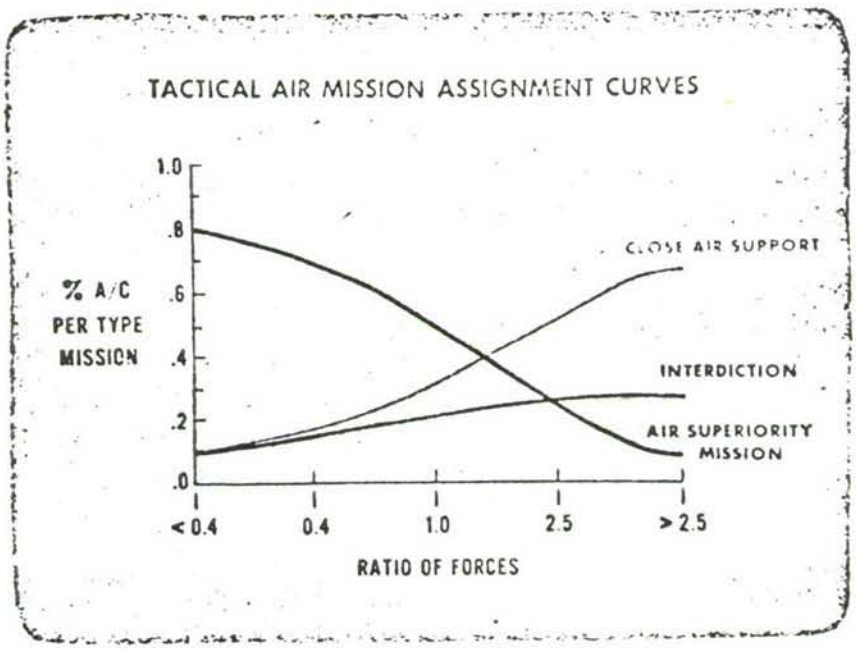


Figure 6-9

TACTICAL DECISION MODEL

The functions of the fourth and last model, the tactical decision model, are shown in Figure 6-10. This model is needed to allow the simulation to proceed through an entire war without interruption. One application of the simulation is to assist in rapid deployment studies, hence in situations where troops, supplies, and equipment will be scheduled to arrive at ports and air bases at various times during a war. This model is specifically designed to determine the sectors to which newly arrived

combat units might best be deployed, to determine the distribution of supplies and missile units as they enter the theater, and to allocate tactical aircraft on a daily basis to each sector for both sides.

The decision model assigns a new unit to a particular sector in the following way: after viewing the type combat actions in all battle sectors, the model determines in which sector the attacking force could reach some predesignated defensive position in minimum time. This position may be a strategic phase line or the enemy's final objective itself. If there is no movement on the front when this assessment is made, minimum distance becomes the criterion instead of minimum time.

Instances may well occur, however, where an additional unit assigned to a sector will overburden the logistics capability of the sector. Therefore, before the new unit is assigned to the sector, the ability of that sector to resupply existing combat units, to transport replacement items and supplies, and to move the new unit through the system is carefully evaluated. If the sector in its present condition is not able to handle the new unit, other sectors are then evaluated as to their capability, always keeping the tactical need foremost in mind.

The allocation of combat aircraft to battle sectors is a function of the tactical situation existing in the sector. Three tactical situations are possible: (1) the aggressor forces advancing, (2) the aggressor forces retreating, and (3) the forces stalemated (i.e., no FEBA movement).



Figure 6-10

These situations are assumed to be assignment priorities in the order 1, 2, 3 for the aggressor force. Thus each day the aircraft are assigned to the highest priority available. If the same situation exists in more than one sector, aircraft are assigned in proportion to the ICE of the opposing force in the sectors involved. Hence any desired change in the logic or priority assignment of aircraft may be made by reordering the above situations.

As supplies enter the theater they may be either earmarked for a specific combat unit or distributed to the various sectors where need is the greatest.

This concludes the description of ATLAS.

7

ILLUSTRATIVE LINKAGES

The individual models discussed in previous sections may be linked together in many different ways depending on the problem to be solved. Two examples of current applications and a third linkage not currently in use are discussed below.

Figure 7-1 illustrates the linkage currently being used in the NATO Combat Capabilities study (COMCAP II). This study is designed to give comparative measures of the effectiveness of different weapon systems and units. A by-product of the analysis is to be the measure of ammunition expenditures of each type.

Company or battalion organizations, weapons performance data, terrain descriptors, and tactics are input to CARMONETTE. Forces played in CARMONETTE cover a range of forces which are expected to be fought in DBM. Since it is impossible to foresee the exact composition of every company/battalion-sized force which might be engaged in DBM, a method of obtaining results of battles not played explicitly in CARMONETTE is required. In this study, COMANEX is used for this purpose.

Using COMANEX to assess the outcomes of small unit ground engagements, DBM simulates the conduct of division-sized operations over a period of several days. Data generated by DBM (with some feedback from the original CARMONETTE battles) are then analyzed to produce the weapons and unit effectiveness values and munitions expended.

A second example of model linkage is shown in Figure 7-2 and is currently being used in the SCAT II study. This effort is designed to evaluate the effectiveness of alternative mixes of helicopters and alternative employment doctrines.

Again, CARMONETTE and DBM are linked together by the COMANEX model. In this case, however, two additional models, DEGAS and EPIC are used. DEGAS assesses the results of engagements between helicopters and ground forces when the ground forces are not concurrently being engaged by opposing ground weapons. DEGAS battle results are also input to the EPIC model to assure consistency between EPIC and DBM.

The output of DBM in this analysis is the logical progression of a division-level campaign to include a time-sequenced list of requirements

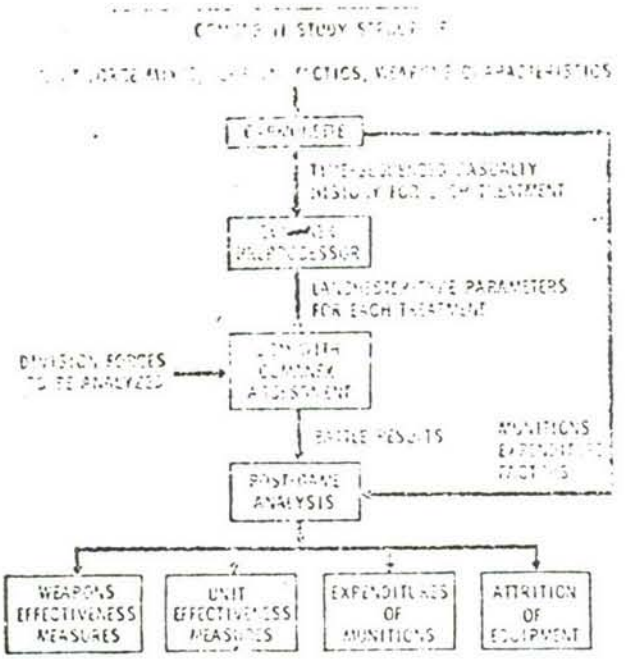


Figure 7-1

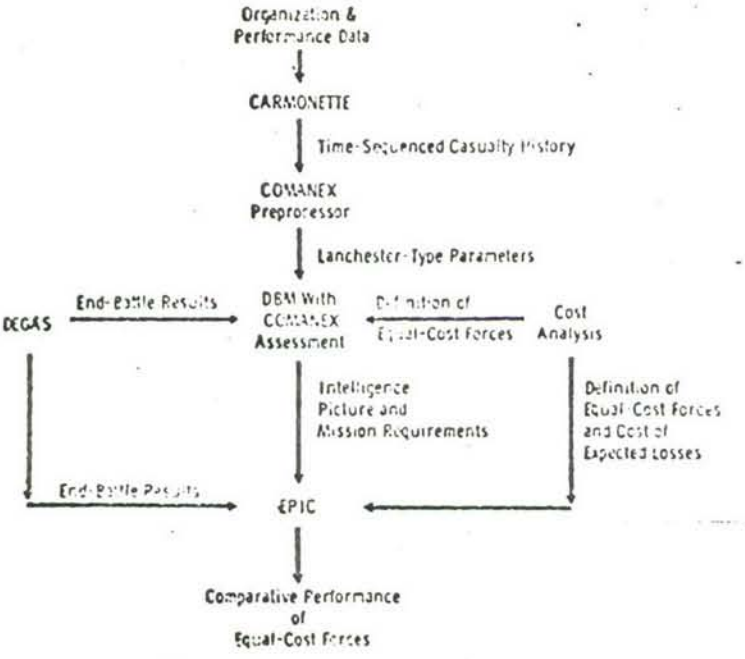


Figure 7-2

for several types of helicopter missions. EPIC projects these division requirements to theater level and, examining local availability, attrition, maintenance cycles, and other factors, determines theater-wide availability and effectiveness of the alternative helicopter mixes.

A third example of a model hierarchy is shown in Figure 7-3. This linkage might be used in a study comparing alternative mixes of divisions in a theater. In this case, the decision involves theater-level effectiveness measurement and a large number of division-level games would be necessary. For this type of analysis, it would be more efficient to use regression equations as the means of loss assessment in DBM since the computer time required is less than with COMANEX. COMANEX could still be used, however, external to DBM, to generate data from which the equations are derived. Independent variables for the regression equations would be numbers of each weapon type involved in the engagement and a separate equation would be derived for assessing each type of loss in which we are interested.

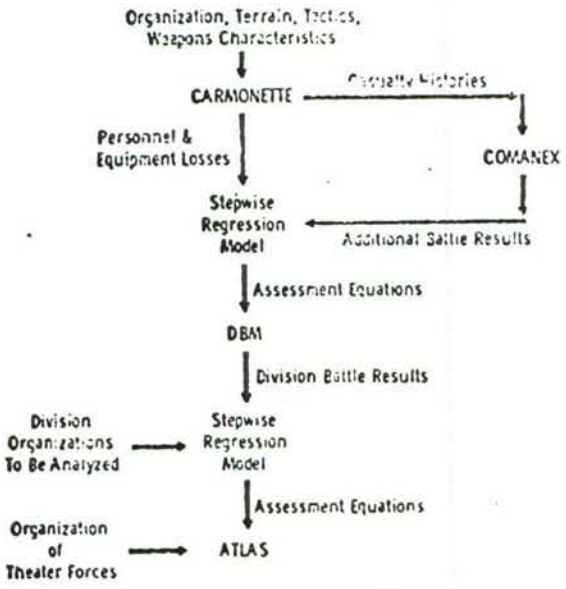


Figure 7-3

Regression might also be used as the interface between DBM and ATLAS. Independent variables in this case might be numbers of each type of battalion involved and the average strength of each (in terms of percent of full strength). Equations could be derived to calculate losses for

each side and, perhaps, movement of the FEBA. Outputs of ATLAS, then, could be used as a basis for evaluating organizational and tactical effectiveness on the theater level.

The flexibility inherent in the ability to structure a hierarchy of models to fit a given problem provides a wide range of possible applications. Some of the more obvious ones are:

1. Mobility - firepower trade-offs.
2. Target acquisition - firepower trade-offs.
3. Evaluation of alternative mixes of tank/antitank systems.
4. Evaluation of alternative tactics for armed helicopters.
5. Evaluation of alternative division organizations.
6. ECM systems for armed helicopter survivability.
7. Evaluation of artillery support families.
8. Armed helicopter vs fixed wing tactical air trade-offs.

CARMONETTE-DIVISION BATTLE MODEL INTERFACE

Mr. R. Glenn Stockton
General Research Corporation
McLean, Virginia

In the Equal Cost Firepower study conducted by Research Analysis Corporation for ACSFOR in 1971 and 1972, a technique was developed for using the results of the CARMONETTE simulation for small unit battles to assess the outcomes of battle in the Division Battle Model (DBM) games. This technique was designed to replace the classical firepower score technique of assessing losses in war games. The results of 518 CARMONETTE replications were used as inputs to a regression analysis to derive the coefficients for a set of assessment equations used in the DBM ground combat routine.

This approach was successful and resulted in creditable casualty assessments in the DBM games in which the losses on each side were a function of the mixes of opposing weapons, tactics, and other factors considered. However, this method had some limitations which precluded its use in the GRC-OAD 1973 work program.

First, the regression procedure requires an extremely large amount of data in order to avoid colinearities among the independent variables. The 518 replications mentioned above represent 74 different treatments of seven replications each. Even this large number of treatments, made possible only by combining the resources for two large studies, is barely adequate when different terrains and postures are considered.

The second, and more important, limitation is that the results of a battle assessment can only be attributed to the mix of weapons involved; target kills by cause cannot be identified.

For the COMCAP II and SCAT II projects, in process at this time for the Department of the Army, a solution for the CARMONETTE-DBM interface has been developed which produces a specific killer-victim matrix for each battle assessed.

The present technique is derived from the COMAN model, developed by Dr. Gordon M. Clark of Ohio State University in 1969, and has been titled COMANEX. COMANEX is a deterministic model based on Dr. Clark's extensions of the classical Lanchester theory of combat. It is a satellite model; it must be used in conjunction with a high resolution combat simulation—in this case, CARMONETTE. Using data from several treatments (battles) of CARMONETTE, COMANEX can assess the results of similar battles at a very small fraction (about .003) of the computer time required for CARMONETTE.

As mentioned above, COMANEX is based on extensions of classical Lanchester theory. Lanchester's two laws of combat are shown in (1) and (2) in terms of differential equations.

$$\frac{dR}{dt} = -bB \qquad \frac{dB}{dt} = -rR \qquad (1)$$

$$\frac{dR}{dt} = - bBR \qquad \frac{dB}{dt} = - rRB \qquad (2)$$

where

R = Number of Red weapons at a given time, t

B = Number of Blue weapons at a given gime, t

b = Rate at which a single Blue weapon kills Red weapons

r = Rate at which a single Red weapon kills Blue weapons.

Equations (1) represent Lanchester's Square Law, which assumes that all targets are visible to all firers, and equations (2) represent the Linear Law which assumes that no targets are visible. These equations are for homogeneous forces (one type of weapon on each side), but can be generalized easily so as to apply to heterogeneous forces. For example, the Linear Law equation for the attrition of Red type 1 weapons would be

$$\frac{dR_1}{dt} = - b_{11}B_1R_1 - b_{21}B_2R_1 -\ldots- b_{n1}B_nR_1 \qquad (3)$$

where

b_{i1} = the rate at which a Blue type i weapon kills Red type 1 weapons

B_i = Number of Blue type i weapons

R_1 = Number of Red type 1 weapons.

Dr. Clark extended the Lanchester formulation by adding a parameter p representing the probability of non-acquisition of a single Red weapon and a set of variables, R_i', defined as the number of Red weapons of priority higher than R_i. The COMAN equation for the attrition of Red type i weapons if then

$$\frac{dRi}{dt} = - b_{1i}B_1(1-p^{R_i})\,p^{R_i} - \ldots - b_{ni}B_n\,(1-p^{R_i})\,p^{R_i}, \qquad (4)$$

where b_{ji} is now defined as the rate at which a Blue type j weapon kills Red type i weapons given that at least one type i is detected and that no weapon of higher priority is detected. For the case, p = 0, this formulation reduces to the Square Law; as p approaches 1, the formulation reduces to the Linear Law. Thus, this set of equations covers the range of combat situations intermediate between the extremes of total target visibility and total invisibility.

COMAN was developed by Dr. Clark as a means of expanding the data base of DYNTACS outputs for tank/antitank battles. In his formulation he assumed that every weapon on each side had the same priority sequence. When we at GRC considered adopting the model as a part of DBM, where assessments were made of about 15 weapon types on each side, it was obvious that this

assumption would not hold. Thus, the original COMANEX computerized assessment model was identical to the COMAN formulation with the added capability of being able to input a discrete priority list for each type of weapon.

COMANEX comprises two basic sub-programs—the preprocessor and the simulator. As originally envisioned, data from each replication of a CARMONETTE treatment, in the form of time-sequenced casualty histories, were input to the COMANEX preprocessor, which output a set of parameters (b_{ji} and p for the equation above) for each of several discrete time intervals of the battle. These parameters are calculated using the statistical principle of "maximum likelihood." Using this technique, a unique set of parameters is obtained that is "most likely" to have produced the results of the CARMONETTE replications of the original force mix. Conceptually, the procedure is analogous to fitting a curve to a set of observed data points by the method of least squares, although the actual mechanics are quite different. In tests of the model it was found that the results of several CARMONETTE treatments differing in mixes of the several weapon types considered, but having in common such things as posture, terrain, and rate of movement, could form the basis of a single set of COMANEX parameters. A library of such parameters is developed for varying terrains and missions and is stored on tape for use in DBM.

In the early tests of the model, although it usually predicted CARMONETTE outcomes, occasionally battle results were predicted which were clearly unreasonable. These anomolies derived from the assumption that each weapon follows the input priority list slavishly. That is, if more than one type of target is detected, the higher priority will always be engaged. Although this is usually the case, CARMONETTE recognizes the contingency that a lower priority target may be posing a grave threat to a firing weapon, in which case he would logically fire at the threatening target. When this happens, the preprocessor computes a very large kill rate (b_{ji}) against the lower priority target. If in a succeeding extrapolation using this set of parameters the number of higher priority targets is severely reduced, this kill rate dominates the entire battle.

To avoid such occurrences in the conduct of a DBM game, we took a step backward from Dr. Clark's formulation and rewrote equation (4) as

$$\frac{dRi}{dt} = - b_{1i} B_1(1-P^{Ri}) - \cdots - b_{ni}B_n(1-P^{Ri}). \qquad (5)$$

This change had the effect of incorporating a sort of firing priority (in terms of fraction of fire at each type of target) into the kill rates. It is recognized that under this formulation one could not extrapolate the parameters from a single treatment of CARMONETTE over as wide a range as was theoretically possible under the original formulation. However, with careful consideration to the CARMONETTE games to be played and the capability to incorporate several games into a single set of parameters, we have had very good results in all tests.

To test the validity of the model in reproducing the results of CARMONETTE games, many comparisons have been made. In every test, COMANEX has produced results quite close to those of CARMONETTE. The results of

one series of such tests are shown in Tables 1 to 6. In this series, six battles represented all possible combinations of three Blue forces (one infantry-heavy, one tank-heavy, and one balanced) and two Red forces (one infantry-heavy and one tank-heavy). All battles had Blue in defense and all were on the same terrain. The output of three of these battles was used to develop a set of COMANEX parameters. These parameters were then used in the COMANEX simulator to reproduce each of the three treatments on which the parameters are based (Tables 1, 2, and 3) and to predict the outcomes of the other three battles (Tables 4, 5, and 6). Results such as these would appear to represent a significant advance over the traditional firepower score method of assessing casualties.

In the current studies, the COMANEX simulator, which actually assesses the outcome of battles, is embedded within DBM as the ground combat subroutine. The DBM gamers specify which numbered units are engaged, the posture (Blue in delay, defense, counterattack, etc.), and break criteria. COMANEX then assesses the results of the battle until a break threshold is reached, or the battle progresses to the end of the CARMONETTE-generated data base. (In practice, DBM battles are seldom permitted to proceed to the point of CARMONETTE termination.) Break criteria include time, personnel casualties, and any combination of equipment losses.

This technique has proven to be an invaluable addition to the conduct of division-level war games. It not only provides assessment on an analytical basis which is intuitively appealing, but it gives the gamers a degree of flexibility impossible to achieve with prior techniques. For example, either or both sides may be reinforced during the course of a battle or the battle may be interrupted at any point for the assessment of an air strike and then resumed. We realize that there are still shortcomings, but while we are working on overcoming them, we feel we have an extremely useful tool representing a large step forward in the state of the art.

Table 1

COMPARISON OF CARMONETTE TREATMENT 3001 AND COMANEX

Blue Losses

Killed by	Tank	TOW	Small Arms
Tank	1/1[a]		
BMP	2/2	1/1	
102 Mortar			3/2
122 HOW			12/12
152 HOW			4/4
122 MRL			0/1

Red Losses

Killed by	Tank	BRDM	BMP	Small Arms
Tank	4/4		6/6	
TOW	6/6	1/1	6/6	
DRAGON	4/4		3/3	
4.2"				1/1
LAW			1/0	
81-mm				1/1
AH	2/2		1/1	
155 How				6/5
8" How				2/2

[a]Number of the left of the slash (/) represents CARMONETTE results; number to the right, COMANEX.

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Table 2

COMPARISON OF CARMONETTE TREATMENT 1101 AND COMANEX

Blue Losses

Killed by	Tank	TOW	Small Arms
Tank	5/5[a]		
BRDM	2/2		
BMP	6/6		
MP SAGGER	2/2		
100 AT	1/1		
120 Mortar			1/1
122 How			4/4
152 How			1/1

Red Losses

Killed by	Tank	BMP	Small Arms
Tank	4/4	10/10	
TOW	2/2	2/2	
DRAGON	2/2	1/1	
4.2"			0/1
81-mm			1/1
AH	2/2	1/1	
155 How			2/4
8" How			2/2

[a]Number of the left of the slash (/) represents CARMONETTE results; number to the right, COMANEX.

Table 3

COMPARISON OF CARMONETTE TREATMENT 3201 AND COMANEX

Blue Losses

Killed by	Tank	Small Arms
Tank	3/3[a]	1/1
BMP	1/1	
120 Mortar		0/2
122 How		8/11
122 MRL		2/2

Red Losses

Killed by	Tank	BMP	Small Arms
Tank	7/6	3/3	
TOW	8/8	2/2	
DRAGON	6/5	1/1	
4.2"			1/1
81-mm			1/1
AH	2/2		
155 How			4/4
8" How			1/1

[a]Number to the left of the slash (/) represents CARMONETTE results; number to the right, COMANEX.

Table 4

COMPARISON OF CARMONETTE TREATMENT 2201 AND COMANEX

Blue Losses

Killed by	Tank	Small Arms
Tank	6/6[a]	
BRDM	1/1	
BMP	1/1	
MP SAGGER	1/1	
122 How		7/8
120 Mortar		0/1

Red Losses

Killed by	Tank	BMP	Small Arms
Tank	6/4	3/5	
TOW	6/6	1/2	
DRAGON	5/4		
AH	2/3		
4.2"			1/1
81-mm			1/1
155 How			3/4
8" How			1/2

[a]Number to the left of the slash (/) represents CARMONETTE results; number to the right, COMANEX.

Table 5

COMPARISON OF CARMONETTE TREATMENT 1201 AND COMANEX

Blue Losses

Killed by	Tank	Small Arms	AH
Tank	9/10[a]	1/0	
BRDM	2/2		
BMP	2/2		
MP SAGGER	1/1		
23/4			1/1
120 Mortar		0/1	
122 How		4/4	

Red Losses

Killed by	Tank	BMP	Small Arms
Tank	10/7	6/7	
TOW	3/3	1/1	
DRAGON	3/2		
4.2"			1/1
81-mm			0/1
AH	2/3		
155 How			3/4
8" How			1/1

[a]Number to the left of the slash (/) represents CARMONETTE results; number to the right, COMANEX.

Table 6

COMPARISON OF CARMONETTE TREATMENT 1201 AND COMANEX

Blue Losses

Killed by	Tank	TOW	Small Arms
Tank	3/3[a]		
BRDM	1/1		
BMP	3/4	1/1	
MP SAGGER	1/1		
100 AT	0/1		
120 Mortar			2/1
122 How			5/8
152 How			2/2
122 MRL			0/1

Red Losses

Killed by	Tank	BMP	Small Arms
Tank	2/3	7/6	
TOW	4/4	6/4	
DRAGON	4/3	1/1	
4.2"			1/1
81-mm			0/1
AH	2/2	1/1	
155-mm			5/5
8" How			3/2

[a]Number to the left of the slash (/) represents CARMONETTE results; number to the right, COMANEX.

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L. DONDERO
GRC
ANTI-ARMOR
WORKSHOP
23 Feb 1984

PANEL 4

ANALYSIS AND SIMULATION TECHNIQUES

Session I

Discussion of Issues

Panel 4 took as its missions both the rationalization of the role of combat simulation in the anti-armor problem and the definition of critical issues relating to the application of simulations to the anti-armor problem at all appropriate levels of analysis.

The basic theme of this report is that the anti-armor problem requires analysis on several different levels, each of which contributes certain insights and findings which cannot be determined at any other single level of assessment. This premise suggests that a hierarchy of models, building from the bottom up instead of the top down, is indispensable to weapons systems evaluation in the ultimate context of the contribution of the weapon system to the overall mission accomplishment of the entire conventional force.

Figure 1 indicates in summary fashion the structure of the hierarchy. Please note that the insights gained from the application of each of the four different levels of analysis are, in a sense, exclusive to each respective level, and that all are necessary to the proper evaluation of the contributions of anti-armor capabilities of the conventional forces.

This is not to say that every time one wishes to consider a new technological contribution to anti-armor capability that it is necessary to go through a lengthy and detailed sequence of model applications, starting at the lower levels and proceeding to the higher. As the literature of analysis accumulates, it is of course feasible to use the results of prior analysis, and it is also true that if the particular component of the antitank capability makes its essential contribution as a theater

mobility weapon rather than a duel weapon, reasonable approximations of its mobility potential may be made without going through the entire hierarchical structure.

Figure 2 is an attempt to relate the existing family of OAD models, including games, simulations, and analytic formulations of simulations, to this hierarchical structure. The main point to make here is that we have had some success in using lower-level simulations such as CARMONETTE, and its analytic version called COMANEX, to perform the combat attrition assessments in the Division Battle Model, which hitherto has been done on the basis of rough force-ratio calculations which determined, from lookup tables, the casualties on each side. Losses and casualties, in effect, were inputs to the Division Battle Model rather than products of it, as they now are. We are also in the process of developing an analytic attrition model called DECAM that is expected to become the combat attrition model of the new GRC theater-operations model called CEM, or CONAF Evaluation Model. Ultimately, in combining CEM and the detailed logistic calculations of EPIC, we envision a theater analytic model as a surrogate of CEM.

Having said this much about our current philosophy of ground combat modeling, I should now like to turn to the critical issues and shortcomings with which we are still confronted.

Figure 3 suggests the broad categories of concern, not all of which are intrinsic to the models themselves or to the computer software. I have made no attempt to organize the specific comments that follow into these categories but you will see that there are enough critical issues to go around, so that each category has several entries.

In looking over the next three figures (4, 5, and 6) which consider deficiencies at the several levels of analysis that we have already discussed, it occurs to me that not much elaboration, if any, is needed for this in-house record. In other words, the items as stated pretty well define the issues and shortcomings for a GRC audience, although we might want to elaborate for another audience. In any event, those of us here in OAD who have experience in combat models are always available to answer questions about items in the figures.

ROLE OF MULTI-LEVEL ANALYSIS

ANALYSIS LEVEL	PROVIDES	DIAGNOSTIC INSIGHTS INTO
TECHNOLOGICAL		CANDIDATE SYSTEM EVALUATION (NECESSARY TO) SYSTEM PERFORMANCE AGAINST DEFENSES * ENGAGEMENT DOCTRINE * VULNERABILITIES * ENVIRONMENTAL INFLUENCES
WEAPON SYSTEM ENGAGEMENT (DUELS)		FORCE ATTRITION COMBINED ARMS SYNERGISMS VALUE OF COMPONENT SYSTEMS TACTICS C^3
COMBINED ARMS ENGAGEMENT (BATTLES)		RESOURCE ALLOCATION TRADE-OFFS MISSION ACCOMPLISHMENT FEBA DYNAMICS? MOBILITY
THEATER OPERATIONS (CAMPAIGNS)		

Figure 1

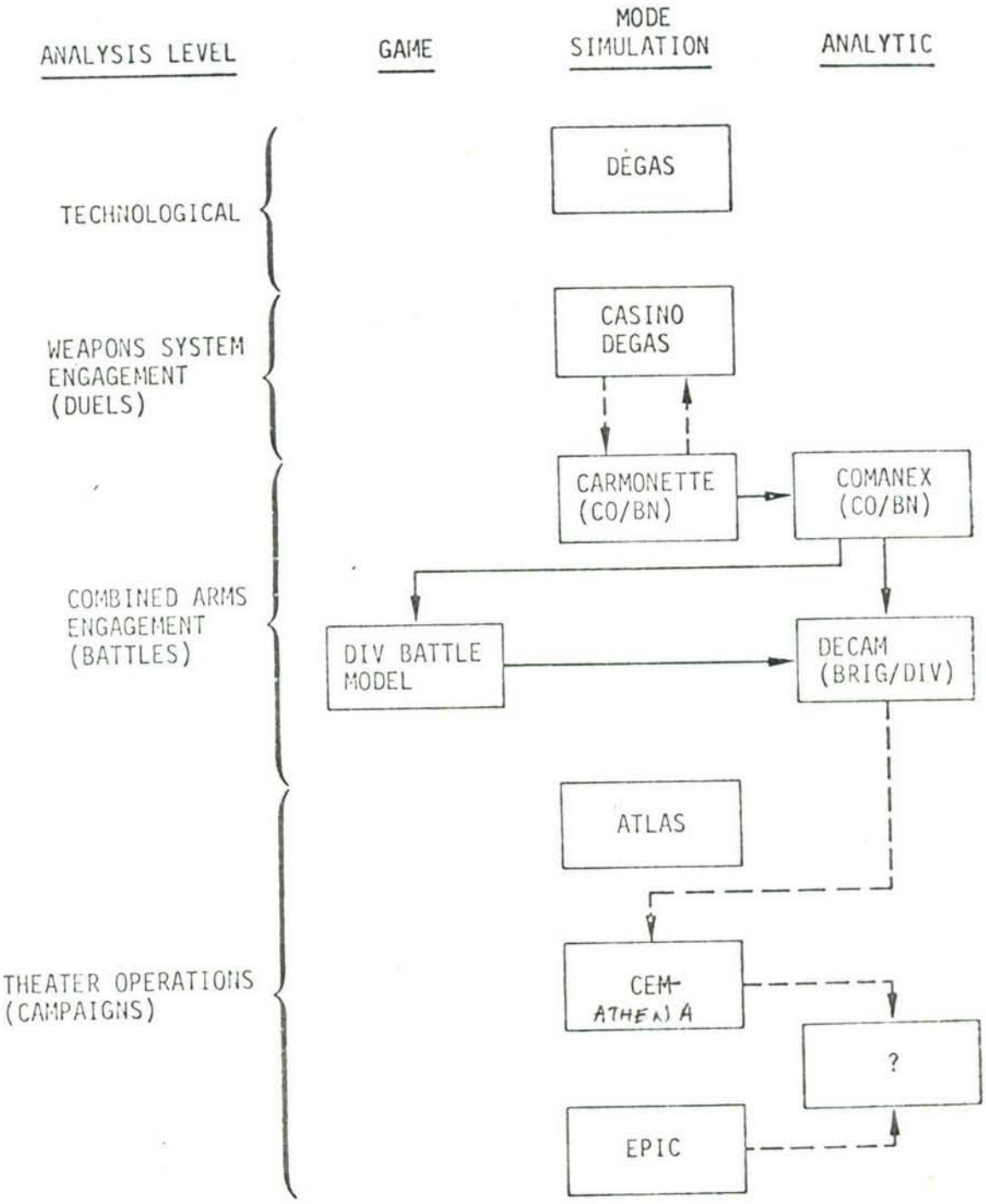

ANALYSIS LEVEL
GAME
MODE
SIMULATION
ANALYTIC
TECHNOLOGICAL
WEAPONS SYSTEM ENGAGEMENT (DUELS)
COMBINED ARMS ENGAGEMENT (BATTLES)
THEATER OPERATIONS (CAMPAIGNS)
DEGAS
CASINO DEGAS
CARMONETTE (CO/BN)
COMANEX (CO/BN)
DIV BATTLE MODEL
DECAM (BRIG/DIV)
ATLAS
CEM
ATHENA
?
EPIC

Figure 2

CRITICAL ISSUES

* DATA BASE PROBLEMS
* MODEL LIMITATIONS
* TYPICAL MODEL APPLICATIONS
* COST OF REALISM vs ECONOMY OF ABSTRACTION
* SOFTWARE "EFFICIENCY"

Figure 3

TECHNOLOGICAL/DUEL MODELS: CRITICAL ISSUES

SUPPRESSION/COUNTERMEASURES

TERRAIN MODELING: LOS AND INTERVISIBILITY

ACQUISITION

VERIFIED COMBAT DATA LACKING

NIGHT/POOR VISIBILITY OPERATIONS; ILLUMINATION

NO BEHAVIORAL ANALYSIS

LIMITED PARAMETRIC EVALUATION

SIMULATORY vs ANALYTIC MODELS

(WILL TECHNOLOGY-RICH SYSTEMS MAKE ISSUES EASIER TO MODEL?)

Figure 4

COMBINED ARMS (BATTLE) MODELS: CRITICAL ISSUES

LIMITED TO STEREOTYPED OPERATIONAL CONCEPTS/DOCTRINE

MODELS NEED MUCH LARGER GEOMETRY (50 x 20 KM) WITH HIGH RESOLUTION (PERHAPS VARIABLE) TERRAIN

DECISION PROCESSES IN MODELS

TIME COMPRESSION

FIXED WING-GROUND COMBAT INTEGRATION

ORTHODOX BATTLES ONLY

OUTCOME VARIABILITY

GAMES/SIMULATIONS/ANALYTIC, OR ALL THREE

LIMITED ALTERNATIVES vs GAME THEORETIC OPTIMUM

Figure 5

THEATER (CAMPAIGN) MODELS: CRITICAL ISSUES

LINEAR FEBA (NO PENETRATION, ENVELOPMENTS, ETC.)

GROSS ALLOCATION DECISION RULES

SINGLE MOE (NO DISCRETE SYSTEMS ROLE, OR DISCRETE LOGISTICS)

FEBA DYNAMICS?

TAC AIR MOBILITY

REAL TIME INTEGRATED INTERDICTION vs CLOSE COMBAT

(EXTANT THEATER PREDICTIVE MODELS QUESTIONABLE TOOLS FOR AT PROBLEM OR FOR TRADE-OFF PROBLEMS IN GENERAL; CEM WILL HELP)

Figure 6

THE QUANTIFIED JUDGMENT METHOD OF ANALYSIS OF HISTORICAL COMBAT

Brief Descriptive Summary

by
Colonel T.N. Dupuy, USA, Ret.

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May 1974

THE QUANTIFIED JUDGMENT METHOD OF ANALYSIS OF HISTORICAL COMBAT[1]

by

Colonel T.N. Dupuy, USA, Retired

Brief Descriptive Summary

The Quantified Judgment Method of Analysis of Historical Combat (QJMA) was developed by the Historical Evaluation and Research Organization, in collaboration with T.N. Dupuy Associates, Inc., for the purpose of providing scholars, military men, and research analysts with a precise means for assessing the relative combat power of two opposing military forces in modern historical combat, and for determining the influence of variable factors on the outcomes of engagements between such forces. While the historiographical significance of being able to make such assessments and determinations is obvious, equally obvious is the contribution which this capability makes to analyses for current military planning and for simulations and wargames used by planners and operations researchers.

The major feature of the QJMA--as a method--is the Quantified Judgment Model (QJM), which is a mathematical simulation of historical combat. The QJM systematically converts recorded statistical and descriptive data on ground combat engagements into quantified assessments of the force strength and combat potential of the opposing sides, thus permitting a ratio of their relative combat power. It does so by modifying the recorded strength of each in men and weapons by values representing the variables of combat, to the extent the record permits. These modifiers include such tangible variables as posture, weather, terrain, air superiority, mobility, logistical effectiveness, and vulnerability, and such intangibles (which can sometimes be assessed from the records) as leadership,

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[1]For a detailed discussion of the QJMA and its rationale, and an explanation of the derivation of the various elements of the QJM, one must refer to the monograph dated 3 May 1972 by Colonel T.N. Dupuy, USA, Ret., entitled: "The Quantified Judgment Method of Analysis of Historical Combat Data."

morale, training, and experience. To permit comparison of the combat power ratio of the QJM with the outcomes of the historical engagements which produced the data, outcomes are represented quantitatively in terms of mission accomplishment, relative spatial effectiveness (ground gaining or holding), and relative casualty effectiveness.

The tabular values which represent some of the variables of combat, and the formulae whereby others are calculated, were derived from tentative values and hypotheses originally established by the application of historically-conditioned professional military judgment to the data assembled for a group of 60 disparate engagements in Italy in 1943-44, in World War II. (It was this application of judgment to data which is suggested by the designation of the method.) These tentative values and hypotheses were refined and readjusted in a painstaking, iterative process until they could be systematically applied to each of the engagements of the data base and, despite the widely varying circumstances of the engagements, give results generally consistent with the actual historical outcomes of those engagements. These refined hypotheses and values were then codified into a set of rules and tables so that in subsequent applications of the method to any given set of engagement data the results would be replicable by any two individuals.

In more than 90 percent of some 81 World War II engagements (including the original 60-engagement data base) in Italy, Northwest Europe and East Europe to which the model has been applied, the value of relative combat power calculated was consistent with the actual quantified historical outcome.[2] A unique aspect of the model is its ability to represent, with similar precision, the effects of close air support and of air interdiction on ground combat.

The Process

The QJMA is applied to historical combat in eight steps. Steps 2 through 6 are parts of a comprehensive formula, or model of historical combat, the QJM. The first step is preparatory; the last two steps are analytical, generally related to an analytical process to determine the implications of the model outcome to whatever special aspect of combat is of immediate concern.

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[2]See Figure V, p. 16, below.

Step 1 - Compiling and Organizing Data

The following categories of data are collected and organized for the QJM:

A. General Information
   1. Beginning and ending dates of engagement; its duration.
   2. Forces involved: Friendly forces, to be identified by the subscript "f"; Enemy forces, to be identified by the subscript "e".
   3. Posture of the opposing forces; one will be the Attacker, identified by the subscript "a"; the other will be the Defender, in one of five defensive postures (hasty defense, prepared defense, fortified defense, delaying action, or withdrawal), identified by the subscript "d".
   4. Description of terrain.
   5. Description of weather.
   6. Assessment of mission accomplishment by each side.
   7. Summary description, to the extent the data permits, of the supply status of each side, if this status appears to be other than "normal."
   8. Summary description, to the extent the data permits, of the nature of the leadership, morale, training, and experience of the opposing forces.

B. Statistics for both sides, as follows:

Infantry weapons, numbers and types to include:	
Small arms	(W_s)[3]
Machine guns	(W_{mg})
Heavy weapons	(W_{hw})
Artillery weapons, number and types	(W_g)
Aircraft types:	
Numbers of close support sorties per day	(W_y)
Numbers of interdiction sorties per day (for use only when logistics effects are to be calculated)	
Armored combat vehicles, number and type	(W_i)
Trucks	(J)
Armored transport vehicles or mobile weapons platforms	(J_i)
Personnel strength	(N)
Depth of deployment area	(D)in kilometers
Casualties incurred per day	(Cas)
Ground gained or lost per day	(Q)in kilometers

[3]These are the symbols used to represent values assigned to these statistical variables.

Step 2 - Calculate Proving Ground Weapons Effectiveness Values

To calculate a basic, or proving ground value for weapons' effectiveness, an Operational Lethality Index (OLI), a form of firepower score, is determined for each of the four categories of weapons listed above (Infantry, Artillery, Armor, Air). Within each of these categories, the OLI for each individual weapon is calculated by consideration of each of the following factors, as related to the design and performance characteristics of the weapon.[4]

1. Rate of fire
2. Number of potential targets per strike
3. Relative incapacitating effect
4. Effective range (or muzzle velocity)
5. Accuracy
6. Reliability
7. Battlefield mobility
8. Radius of action
9. Punishment factor
10. Dispersion factor

(7, 8, 9: For "Mobile Fighting Weapons," as tanks and aircraft)

Step 3 - Determining Variables (Environmental and Operational)

Since there is no way of determining absolute values for the variables which operate in combat, the QJM uses relative values which are actuarial in nature, derived from observation, from historical analysis, and from the influence each variable normally exerts on the element it affects. The variables are of two types, environmental and operational.

Environmental variables are those that influence the effectiveness of weapons. There are four kinds of environmental variables, to each of which values are assigned related to the elements that they modify:

1. Terrain (see Table 1)
2. Weather (see Table 2)
3. Season (see Table 3)
4. Presence or absence of air superiority (see Table 4)

Operational variables are those that affect the employment of weapons, or of a military force as a whole. There are ten general categories of operational variables, some of which are assigned relative values, and for some of which values must be calculated.

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[4]See Appendix A for a sample World War II list of weapons OLIs.

TABLE 1. TERRAIN FACTORS (r)

Terrain Characteristics	Mobility r_m	Defense Position[1] r_u	Infantry Weapons[2] r_n	Arty r_{wg}	Air r_{wy}	Tanks r_{wi}
Rugged-- Heavily Wooded	0.4	1.5	0.6	0.7	0.8	0.2
Rugged-- Mixed	0.5	1.55	0.7	0.8	1.0	0.3
Rugged-- Bare	0.6	1.45	0.8	0.9	1.0	0.5
Rolling-- Heavily Wooded	0.6	1.35	0.8	0.8	0.9	0.6
Rolling-- Mixed	0.8	1.45	0.9	0.9	1.0	0.8
Rolling-- Bare	1.0	1.3	1.0	1.0	1.0	1.0
Flat-- Heavily Wooded	0.7	1.1	0.8	0.9	0.9	0.7
Flat-- Mixed	0.9	1.2	0.9	1.0	1.0	0.9
Flat-- Bare	1.0	1.05	1.0	1.0	1.0	1.0

[1]For all defense postures; Attacker is always 1.0.

[2]Applied to small arms, machine guns and other infantry weapons.

TABLE 2. WEATHER FACTORS (h)

Weather Characteristics	Mobility h_m	Attack h_{ua}	Artillery h_{wg}	Air h_{wy}	Tanks h_{wi}
Dry - Sunshine - Extreme Heat	0.9	1.0	1.0	1.0	0.9
Dry - Sunshine - Temperate	1.0	1.0	1.0	1.0	1.0
Dry - Sunshine - Extreme Cold	0.9	0.9	0.9	1.0	0.9
Dry - Overcast - Extreme Heat	1.0	1.0	1.0	0.7	1.0
Dry - Overcast - Temperate	1.0	1.0	1.0	0.7	1.0
Dry - Overcast - Extreme Cold	0.9	0.9	0.9	0.7	0.8
Wet - Light - Extreme Heat	0.9	0.9	0.9	0.5	0.7
Wet - Light - Temperate	0.8	0.9	1.0	0.5	0.7
Wet - Light - Extreme Cold	0.8	0.9	1.0	0.5	0.7
Wet - Heavy - Extreme Heat	0.5	0.6	0.9	0.2	0.6
Wet - Heavy - Temperate	0.6	0.7	0.9	0.2	0.5
Wet - Heavy - Extreme Cold	0.5	0.6	0.8	0.2	0.5

TABLE 3. SEASON FACTORS (z)

Seasonal Variations	Attack z_u	Artillery z_{wg}	Air z_{wy}
Winter - Jungle	1.1	0.9	0.7
Winter - Desert	1.0	1.0	1.0
Winter - Temperate	1.0	1.0	1.0
Spring - Jungle	1.1	0.9	0.7
Spring - Desert	1.0	1.0	1.0
Spring - Temperate	1.1	1.0	0.9
Summer - Jungle	1.1	0.9	0.7
Summer - Desert	1.0	1.0	1.0
Summer - Temperate	1.1	0.9	1.0
Fall - Jungle	1.1	0.9	0.7
Fall - Desert	1.0	1.0	1.0
Fall - Temperate	1.1	1.0	0.9

Defender is always 1.0.

TABLE 4. EFFECTS OF AIR SUPERIORITY (y)

	Mobility m_{yd}	Mobility m_{yw}	Artillery w_{yg}	Air w_{yy}	Vulnerability v_y
Air Superiority	1.0	1.0	1.1	1.1	0.9
Air Equality	1.0	1.0	1.0	1.0	1.0
Air Inferiority	0.9	1.0	0.9	0.8	1.1

Subscript d for dry or flyable weather; w for wet weather when h_{wy} is .5 or lower.

TABLE 5. POSTURE FACTORS (u)

	Force Strength u_s	Vulnerability u_v
Attack	1.0	1.0
Defense (hasty)*	1.3	0.7*
Defense (prepared)*	1.5	0.6*
Defense (fortified)*	1.6	0.5*
Withdrawal	1.15	0.85
Delay	1.4	0.65

*In an amphibious assault, or assault across a major or unfordable river, add .1 to u_s, subtract .1 from u_v.

1. Terrain. Table 1 relates terrain values to mobility and posture.
2. Weather. Table 2 relates weather to mobility and posture.
3. Season. Table 3 relates season to posture.
4. Presence or absence of air superiority. The effect of air superiority on mobility and vulnerability is shown in Table 4.
5. Posture. Table 5 relates defensive preparation to force capability and to vulnerability.
6. Relative mobility of the two forces is calculated, with respect to opposing force characteristics and the environment at the time of the engagement, as follows:

a. The attacker's mobility characteristics (M_a) are determined by the following formula:

$$M = \sqrt{/\overline{(N_a + 20J_a - W_{ia}) \times m_{ya}/N_a/}//\overline{(N_d + 20J_d + W_{id}) \times m_{yd}/N_d/}} \quad (1)$$

N is personnel strength.
J is the vehicle strength, plus twice the number of non-combat armored vehicles (J_i).
W_i is the consolidated combat armored vehicle OLI.
m_y is the effect of air superiority on mobility, see Table 4.
The value of M for the defender (M_d) is always 1.

b. The attacker's resulting mobility characteristics are modified by the effects of environmental conditions through the following formula, to get his mobility factor:

$$m_a = M_a - (1 - r_m \times h_m)(M_a - 1) \quad (2)$$

r_m is the effect of terrain on mobility, see Table 1.
h_m is the effect of weather on mobility, see Table 2.
The value of m_d is always 1.

7. The vulnerability of each side, under the existing circumstances, and in the light of the characteristics of the opposing forces, is calculated as follows:

a. The vulnerability characteristics (v) are determined by the following formula:

$$V = N \times c \times \sqrt{S_e/S_f} \times v_y \times v_r \quad (3)$$

N is personnel strength
c is exposure, expressed as a relationship between the vulnerability effects of posture (u_v, see Table 5) and the terrain effects of posture (r_u, see Table 1) $c = u_v/r_u$.
S is the Force Strength as calculated in Step 4, below.
v_y is the effect of air superiority on vulnerability, see Table 4.
v_r is the effect of shore line vulnerability in an amphibious or river-crossing operation, see Table 6.

TABLE 6. SHORELINE VULNERABILITY FACTORS

Hostile Fire on Shore Line	Across Beach	Across Unfordable River	Across Major Fordable or Minor Unfordable River
Small Arms Fire (up to 1,000 meters from shore)	2.0	1.5	1.3
Light Artillery (up to 10,000 meters from shore)	1.6	1.3	1.1
Medium Artillery (up to 15,000 meters from shore)	1.3	1.1	1.0

b. The vulnerability factor (v) for each side is determined as follows:

$$v = 1 - V/S \qquad (5)$$

V is the vulnerability characteristic, as calculated above.
S is the Force Strength.

8. Tactical air effects. The operational impact of an air superiority environment upon both mobility and vulnerability are discussed above; the only other exclusively operational tactical air effect variable in the QJM is the degrading effect of air interdiction upon logistical capability.

9. Other combat processes effects. To date only a few of the presumably extensive number of potentially quantifiable combat processes have been identified and tentatively quantified. Among these few are shore line vulnerability in amphibious and river-crossing operations (see Table 6), surprise (see Table 7), the interaction of opposition with rates of advance,[5] the interaction of obstacles effects with posture, terrain, and mobility,[6] and the effects of casualties and fatigue on combat effectiveness.[7] This is an area of great promise for future research, possibly only with the use of the QJMA.

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[5]See HERO study report, "Opposed Rates of Advance of Large Forces in Europe (ORALFORE)," August 1972.

[6]See HERO study report, "Historical Evaluation of Barrier Effectiveness," March 1974.

[7]See HERO study report, "Manual of Historical Data for Inputs to and Development of Air and Ground Combat Simulation Models," March 1973, p. 174.

TABLE 7. TENTATIVE TACTICAL SURPRISE FACTORS (sur)

	Surpriser's Inherent Mobility Characteristics (M_{sur})	Surpriser's Vulnerability (V_{sura})	Surprised Vulnerability (V_{surd})
Complete Surprise	5.0	0.4	3.0
Substantial Surprise	3.0	0.6	2.0
Minor Surprise	1.5	0.8	1.5

10. Intangibles. Depending upon the data in the records, values are assigned to the following intangible variables:

a. Leadership is assumed to be 1 for each side, unless there is reason for assignment of a lesser factor on the basis of qualified professional judgment applied to the available historical data.

b. Training and/or experience also is always represented as 1, unless another value can be assigned on the basis of qualified professional judgment and the record. If there is reason, on the basis of other calculations using an adequate data base, to assess combat effectiveness values for the opposing forces, the relative value is applied here.

c. Morale is handled exactly like the factors for leadership and for training/experience; for an example see Table 7.

d. Logistics values may be assessed by professional judgment in the same manner as for the three previous intangibles, or (as noted above) may be calculated from analysis of the effects of air interdiction under certain circumstances. (So far this has been done with the QJMA only for Italy in 1944.)

Step 4 - Calculating Force Strength

The overall Force Strength (S) of each side is calculated as follows:

A. To the composite OLIs of each weapons category, appropriate environmental variables from the several tables are applied as follows:

1. Terrain effects on infantry weapons (r_n), see Table 1.
2. Terrain effects on artillery (r_{wg}), see Table 1.
3. Weather effects on artillery (h_{wg}), see Table 2.
4. Seasonal effects on artillery (z_{wg}), see Table 3.
5. Air superiority effects on artillery (w_{yg}), see Table 4.

6. Terrain effects on armored vehicles (r_{wi}), see Table 1.
7. Weather effects on armored vehicles (h_{wi}), see Table 2.
8. Terrain effects on close air support (r_{wy}), see Table 1.
9. Weather effects on close air support (h_{wi}), see Table 2.
10. Seasonal effect on close air support (z_{wi}), see Table 3.
11. Air superiority effects on close air support (w_{yy}), see Table 4.

B. The resultant environmentally-modified OLIs are consolidated into a single Force Strength, or refined Firepower, value (S), for each side.

Step 5 - Calculating Combat Power (Potential)

The Combat Power, or Combat Potential (P), of a force is calculated by applying each of the applicable operational variables as determined in Step 3, to the Force Strength (S) of each side, as calculated in Step 4. The resultant number is, in effect, a refined OLI, or firepower value, for the given force under the specific circumstances of combat of the engagement being analyzed. See Figure I, The Quantified Judgment Method Formula.

Step 6 - Calculating Friendly/Enemy Combat Power Ratio

The relative combat potential of the two opposing sides in the engagement is determined by the simple ratio: P_f/P_e.

From this one can determine which side should theoretically have won the engagement, on the basis of the historical data available. A value greater than 1 indicates that the enemy force should have been successful. Ratios between 1.05 and 0.95 are considered to be indeterminate.

Step 7 - Determining and Quantifying Actual Engagement Outcome

The historical outcome of an engagement is quantified by applying quantified values to three critical measures of combat success for each side:

1. Mission Accomplishment is assessed judgmentally by the experienced military historian in terms of the degree to which the force accomplished its assigned or perceived mission, under the circumstances of the engagement. The standard values for Mission Factors (MF) are to be found in Table 8.

2. The measure of a combat force's spatial effectiveness (E_{sp}) in gaining or holding ground considers both the relative strengths of the two forces, and the relative depths of the areas occupied by

Figure I

QJM -- MODEL FORMULA

$$S_f = (W_s + W_{mg} + W_{hw}) \times r_h + (W_g \times r_{wg} \times h_{wg} \times z_{wg} \times w_{yg}) + (W_i \times r_{wi} \times h_{wi})$$

(INFANTRY) + (ARTILLERY) + (ARMOR)

$$+ (W_y \times r_{wy} \times h_{wy} \times z_{wy} \times w_{yy})$$

+ (CLOSE AIR SUPPORT)

$$M_a = \sqrt{[(N_a + 20J_a + W_{ia}) \times m_{ya}/N_a] / [(N_d + 20J_d + W_{id}) \times m_{yd}/N_d]}$$

(RELATIVE MOBILITY CHARACTERISTICS)

$$m_e = M_a - (1 - r_m \times h_m)(M_a - 1) \quad \text{(MOBILITY FACTOR)}$$

$$v_f = 1 - (N \times u_v / r_u \times \sqrt{S_e/S_f} \times v_y \times v_h / S_f) \quad \text{(VULNERABILITY FACTOR)}$$

$$P_f = S \times m \times l_e \times t \times o \times b \times u_s \times r_u \times h_u \times z_u \times v \quad \text{(FRIENDLY POWER POTENTIAL)}$$

$$P_e = S \times m \times l_e \times t \times o \times b \times u_s \times r_u \times h_u \times z_u \times v \quad \text{(ENEMY POWER POTENTIAL)}$$

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TABLE 8. MISSION FACTORS

	Range	Normal
Complete accomplishment of the mission, a weight of	7-10	8
Substantial, relatively satisfactory, accomplishment	5-7	6
Partial, less than satisfactory, accomplishment	3-5	4
Little achievement of the mission	1-3	2

each (D), in comparison to the distance of advance or withdrawal (Q), as ground changes hands during the course of the engagement. The empirically-derived formula (for the friendly side) is:

$$E_{fsp} = \sqrt{(S_e \times u_{se})/(S_f \times u_{sf}) \times (4Q + D_e)/3D_f} \quad (6)$$

3. Casualty Effectiveness (E_{cas}) is a calculation of the effectiveness of the force in inflicting and sustaining casualties, under the circumstances of the engagement, in comparison with the casualty effectiveness of the opposing side. It is determined from the following empirically-derived formula (for the friendly side):

$$E_{fcas} = v_e^2 \left(\sqrt{Cas_e/Cas_f \times S_f/S_e \times u_{sf}/u_{se}} - \sqrt{100Cas_f/N_f}\right) \quad (7)$$

4. A Result value (R) for each side is obtained by algebraically adding each of the three critical measures of combat success:

$$R = MF + E_{sp} + E_{cas} \quad (8)$$

5. An Outcome value is obtained by subtracting the Result value of the enemy force (R_e) from the Result value of the friendly force (R_f). Thus

$$\text{Outcome} = R_f - R_e \quad (9)$$

If the Outcome value is positive, it reflects a friendly success; if it is negative, the engagement was an enemy success. Values in the range of + 0.5 to - 0.5 are considered to be inconclusive. A ratio cannot be used since negative values for R are possible.

Step 8 - Comparing Theoretical and Actual Outcomes

The outcome value ($R_f - R_e$) is compared with the Combat Power Ratio (P_f/P_e). When P_f/P_e is greater than unity, the outcome ($R_f - R_e$)

would be expected to be a positive value; when the ratio is less than unity, the outcome value would be expected to be negative. When these are not consistent with each other, there is an obvious need for further analysis to determine the reason for the inconsistency.

Before considering the extent of consistency that has been found in making these comparisons with 81 historical engagements, it will be helpful to go into some more detail on the critical matter of the effects of variables on weapons, and then to note the performance of all eight operations in one historical example.

Applying Variables to Historical Weapons and Forces

Sample Applications

Figure II shows the effects of the application of the most common variables to the proving ground OLI of a typical World War II weapon, an M-4 Medium Tank, in four kinds of situations: (1) attack under favorable circumstances; (2) attack under unfavorable circumstances; (3) defense under favorable dircumstances; and (4) defense under unfavorable circumstances. Note how the proving ground OLI value of 302 is modified in each of these different circumstances.

Figure II. APPLICATION OF QJMA VARIABLES TO M-4 MEDIUM TANK

Factors	Attack		Defense	
	Favorable	Unfavorable	Favorable	Unfavorable
ENVIRONMENTAL				
W_i (OLI Value)	302.0	302.0	302.0	302.0
Terrain	0.9	0.3	0.9	0.3
Weather	1.0	0.3	1.0	0.3
Force Strength (S)	271.8	27.2	271.8	27.2
OPERATIONAL				
Mobility	1.2	0.8	1.2	0.8
Vulnerability	0.9	0.7	0.9	0.7
Posture	1.0	1.0	1.6	1.6
Terrain	1.0	1.0	1.4	1.2
Weather	1.0	0.8	1.0	0.8
Season	1.1	1.0	1.0	1.0
Intangibles	1.0	1.0	1.0	1.0
Combat Potential (P)	322.9	12.2	664.8	23.4

Figure III shows the effects of applying the variables in these same four kinds of situations for four historical weapons of World War II; (1) the tank (repeated); (2) 60mm mortar; (3) 105mm howitzer; and (4) P-47 fighter bomber.

Figure III. SAMPLE VARIABLE EFFECTS UPON SELECTED WORLD WAR II WEAPONS

	Attack		Defense	
	Favorable	Unfavorable	Favorable	Unfavorable
M-4 Medium Tank				
Unmodified OLI	302.0	302.0	302.0	302.0
Variables Applied	322.9	12.2	664.8	23.4
60mm Mortar				
Unmodified OLI	58.0	58.0	58.0	58.0
Variables Applied	62.0	18.2	126.3	34.9
105mm Howitzer				
Unmodified OLI	252.0	252.0	252.0	252.0
Variables Applied	329.3	65.9	670.6	126.4
P-47 Fighter Bomber				
Unmodified OLI	416.0	416.0	416.0	416.0
Variables Applied	543.6	24.1	1,107.0	46.4

Figure IV shows the application of all eight basic QJMA operations to a typical compilation of combat data: the crossing of the Seine River by the US XX Corps on 23-25 August 1944.[8]

Tables and Forms

As noted in the discussion of Steps 4 and 5, above, most of the environmental and operational variables used in the QJM are in tables which have been developed empirically from World War II data (Tables 1 - 8). As discussed in Step 5, two of the operational variables (mobility and vulnerability) are calculated by formulae combined with tables.

For systematic and consistent application of the QJMA to engagement data, two forms are required: (1) a data compilation form and (2) a model calculation form.

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[8]The data relevant to this example is contained in HERO study report, "Opposed Rates of Advance of Large Forces in Europe (ORALFORE)," August 1972, p. E-37.

Model Formula

$S_f = (W_s + W_{mg} + W_{hw}) \times r_n + (W_g \times r_{wg} \times h_{wg} \times z_{wg} \times w_{yg}) + (W_i \times r_{wi} \times h_{wi}) + (W_y \times r_{wy} \times h_{wy} \times z_{wy} \times w_{yy})$

$(8124 + 5060 + 75{,}40?) \times .9 + (77{,}740 \times .9 \times 1 \times .9 \times 1.1) + (144{,}756 \times .8 \times .7) + (8833 \times 1 \times .5 \times 1 \times 1.1)$

$= 79{,}729 + 69{,}266 + 81{,}0?? + 4{,}858 = \underline{234{,}91?}$

$M_a = \sqrt{[(N_a + 20J_a + W_{ia}) \times m_{ya}/N_a] / [(N_d + 20J_d + W_{id}) \times m_{yd}/N_d]}$

$\sqrt{(40{,}619 + 20 \times 7717 + 144?8) \times 1/40{,}619 \;/\; (15{,}000 + 20 \times 2300 + 13472) \times 1/15{,}000}$

$= \sqrt{1.6846} = 1.298$

$m_a = M_a - (1 - r_m \times h_m)(M_a - 1)$

$1.298 - (1 - .8 \times .8)(.298) = 1.190$

$V_F = 1 - (N \times u_v / r_u \times \sqrt{S_e / S_F} \times v_y \times v_r / S_f)$

$1 - (40{,}619 \times 1/1 \times \sqrt{.170?} \times .9 \times 1.2^{*}/234.9?) = .4229$

$P_f = S \times m \times l_e \times t \times o \times b \times u_s \times r_u \times h_u \times z_u \times V$

$234916 \times 1.1907 \times 1 \times .8 \times 1 \times 1 \times 1 \times ? \times 1 \times .9224$

$= \underline{204{,}424}\ (P_f)$

$S_e = (W_s + W_{mg} + W_{hw}) \times r_n + (W_g \times r_{wg} \times h_{wg} \times z_{wg} \times w_{yg}) + (W_i \times r_{wi} \times h_{wi}) + (W_y \times r_{wy} \times h_{wy} \times z_{wy} \times w_{yy})$

$(3000 + 859 + 17{,}460) \times .9 + (18{,}37? \times .7 \times 1 \times .9 \times .9?) + (13{,}472 \times .8 \times .7) + 0 = \underline{40{,}127}\ (S_e)$

$V_e = 1 - (N \times u_v / r_u \times \sqrt{S_f / S_e} \times v_y \times v_r / S_e)$

$1 - (15{,}000 \times .6/1.45 \times \sqrt{5.854?} \times 1 \times 1 \times 1/40{,}127) = .5?$

$P_e = S \times m \times l_e \times t \times o \times b \times u_s \times r_u \times h_u \times z_u \times V$

$40{,}127 \times 1 \times 1 \times 1 \times 1 \times 1 \times 1.5 \times 1.45 \times 1 \times 1 \times .588?$

$= \underline{51{,}354}\ (P_e)$

* value selected because factual situation

$P_f / P_e = \underline{3.98}$

Result Formula

NF_f — 9

$E_{fsp} = \sqrt{(S_e \times u_{se}) / (S_f \times u_{sF}) \times (4Q + D_e) / 3D_F}$

$\sqrt{(.1708 \times 1.5 \times 4 \times 127 + 91)/3 \times 247} = 4.$

$E_{fcas} = v_e^2 (\sqrt{Case / Cas_f} \times S_f / S_e \times u_{sF} / u_{se} - \sqrt{100\ Cas_F / N_f})$

$.3461 (\sqrt{30278 \times 5.8543 \times 1/15} - \sqrt{7800/40.614}) = 1.19$

$R_F = MF_f + E_{fsp} + E_{fcas}$

$9 + .455 + 1.19 = \underline{10.65}$

MF_e — 2

$E_{esp} = \sqrt{(S_f \times u_{sF}) / (S_e \times u_{se}) \times (4Q + D_f) / 3D_e}$

$\sqrt{3.9032 \times (-4 \times 127 + 247)/3 \times 91} = 1.3$

$E_{fcas} = v_f^2 (\sqrt{Cas_F / Case} \times S_e / S_f \times u_{se} / u_{sf} - \sqrt{100\ Case / N_e})$

$.8516 (\sqrt{.2583 \times .1708 \times 15} - \sqrt{30200/15000}) = -.99$

$R_e = MF_e + E_{esp} + E_{ecas}$

$2 - 1.93 - .99 = -0.92$

$R_f - R_e = \underline{11.57}$

Figure IV

Results of Historical Analyses

To date 81 engagements of World War II have been analyzed by the QJMA, with results as shown in Figure V. It should be noted that there was a slightly higher percentage of correct predictions with the 21 engagements to which the method has most recently been applied, than with the 60 engagements which were originally used to develop and refine the method. To be specific on the first line of Figure V, for the 60-engagement data base the percentage of correct predictions was 91.7%, for the 21 additional engagements it was 95.2%.

Figure V. RESULTS OF QJMA - 81 ENGAGEMENT DATA BASE

	Totals	Correct Predictions	Incorrect	Percent Correct
1. Including unpredictable* and inconclusive**	81	75	6	92.6
2. Eliminating unpredictable which were also inconclusive	77	71	6	92.2
3. Eliminating all unpredictable	69	63	6	91.3
4. Eliminating inconclusive	72	67	5	93.1
5. Eliminating all unpredictable and all inconclusive	65	60	5	92.3

* $P_f/P_e > 0.90$ or < 1.10 **$R_f - R_e > -0.50$ or < 0.50

The Unique Characteristics of the QJMA and the QJM

The QJMA is an actuarial approach to the use of historical combat data. This is an approach just as valid for military analysis of individually unpredictable variables as it is for life insurance, and for the behavioral scientists' analyses of comparable individually unpredictable variables. In a reasonably large data base it has been demonstrated that mean or average values for these variables can be predicted with great reliability.

Consideration is given in the QJMA to all identifiable variables of significance in combat. The results of the analyses--as seen in the comparison of theoretically predicted and actual outcomes in the previous figure--provides a basis for high confidence in the method's

success in representing the variables of combat. Such confidence is not possible with any other known model. For the first time the analyst has a reliable, validated, quantitative theory of combat structure.

The QJMA realistically represents the influence of air support on the land battle in the following respects:

1. The direct augmentation by air armament of the firepower inventory of the supported troops;

2. The positive effects of air superiority on supported troops.
   a. Improved mobility,
   b. Reduced vulnerability, and
   c. Increased artillery effectiveness;

3. The negative effects of air superiority on opposing troops:
   a. Reduced effectiveness of close air support,
   b. Decreased mobility,
   c. Increased vulnerability, and
   d. Reduced artillery effectiveness;

4. The logistical degradation, and thus reduced combat effectiveness, resulting from air interdiction.

The QJMA has for the first time permitted analyses of historical data by means of relating combat processes, or special combat situations, to the normal interaction of variables. The following are examples of such use of the QJMA as an analytic tool:

1. Evaluation of intensity of combat (a matter that has long baffled operations research analysts)

2. Determination of casualty-inflicting capability

3. Calculation of standard, or normalized, rates of advance

4. Development of hypotheses on quantified effects of obstacles

5. Development and testing of hypotheses on quantified effects of surprise

6. Calculation of effects of casualties and fatigue on combat effectiveness

7. Determination of effects of naval gunfire support on amphibious operations.

Appendix A

WEAPONS EFFECTIVENESS
(Operational Lethality Indices - OLI)

American Weapons, World War II		German Weapons, World War II	
Rifle, Pistol, Carbine	0.2	Rifle, Pistol, etc.	0.2
Light Machine Gun (LMG) including BAR	1.0	Light Machine Gun (LMG)	1.0
Heavy Machine Gun (HMG) including .50 cal.	2.2	Heavy Machine Gun (HMG)	2.2
Mortars: 60mm	126	Mortars: 60mm	126
81mm	126	81mm	126
4.2"	244	120mm	245
2"	10	AA/AT, 20mm	12
Rocket Launcher	9	AT, 20-50mm	25
Gun AT, 57mm	27	Flame Thrower	1.0
Gun AT, 3"	136	Panzerfaust	9
Gun, AAA, 40mm, or quadruple mount .50 cal.	25	Infantry Howitzer, 150mm	167
Gun, AAA, 90mm	130	AA/AT, 75mm	195
Howitzer, 75mm	113	AA/AT, 88mm	210
Howitzer, 105mm	239	100mm Gun	256
Gun, 4.5"	250	105mm Howitzer	239
Howitzer, 155mm	304	105mm Gun	270
Gun, 155mm	365	122mm Gun	290
Howitzer, 8"	264	150mm Howitzer	300
Gun, 8"	316	150mm Gun	350
Howitzer, 240mm	250	170mm Gun	315
Flame Thrower	1.0	150mm Nebelwerfer	426
Car, Armored	43	210mm Nebelwerfer	390
Tank Destroyer	240	Car, Armored	43
Tank, Light	243	TD/SP Guns, 88-100mm	265
Tank, Medium	334	Tank, Mk IV	352
		Tank, Mk V	421
		Tank, Mk VI	445
Fighter-Bomber, P-47, P-38	500	Fighter-Bomber, M-109, FW-190	471

Application of QJMA to Current Force Assessments

The QJMA was developed to permit more selective analyses of combat processes, and of the interaction of the variables of combat, than is possible with any other known method. It was not intended as a predictive tool, and in its present form it is not predictive.

However, there is a sound rationale behind recent efforts to adapt this tool of retrospective analyses to assessment of the relative combat effectiveness of current forces in realistic hypothetical combat situations. This rationale is summarized as follows:

1. There has been a continuum of consistency in relationship of weapons performance to weapons characteristics, as reflected in the OLI calculations, from the dawn of history through World War II. This continuum of consistency has had several discontinuities in weapons power and effectiveness. Despite the quantum jump in power and complexity from the handaxe or the longbow to the atomic bomb and the guided missile, the OLI concept permits a direct mathematical relation between the weaponry of ancient history and of World War II. There is therefore every reason to believe that the OLI concept of calculating weapons effectiveness can be adapted to represent the relative effectiveness of the gamut of weapons in current use.

2. Aside from weapons characteristics, the general interrelationship of variables, as developed for the QJM, has apparently been valid when applied to engagements within a 139 year period from 1805 through 1944, and has been just as reliable in representation of battles without air power and without tanks, as battles with air power and with tanks. It is quite unlikely that there would be any sudden discontinuity in this validity--at least in conventional combat--in the last 30 years.

3. At least four major variables of combat remain undeniably relevant to combat performance:

a. Human response to conflict circumstances and challenges, as reflected in such things as fatigue, effects of casualties on combat capability, disruption, etc.;

b. Terrain, as it affects fields of fire, mobility, vulnerability, etc.;

c. Weather, as it affects visibility, movement, etc.;

d. Season, as it affects hours of daylight, density of foliage, etc.

4. There is an apparent or reasonably likely continuing relevance in other variables of combat:

a. Relative mobility as an influence on combat effectiveness;

b. Vulnerability, as it affects the relative capabilities of attacker and defender;

c. The enhancement or degradation effects of posture, and defensive preparations and fortifications, on the capabilities of attacker and defender;

d. The similar effects of air superiority on the opposing sides;

e. Such combat processes as movement rates in relation to opposition, effects of surprise, and the effects of obstacles on attacker and defender;

f. The historical dynamic relationship which has existed among firepower, dispersion, and movement capability--a fundamental basis for the whole QJMA concept.

In order to relate the method to current force capability assessments, reasonable OLI calculation modifications have to be made to reflect modern weapons characteristics, and ways must be found to include such weapon elements as helicopters and APCs. Toward this end, some refinements have already been made in OLI calculation procedures, to reflect significant characteristics of modern weapons. The nature of these refinements is shown on Figure VI. These modifications need to be checked more thoroughly with weapons specialists and evaluators, but a presentation to a MORS Measures of Effectiveness Working Group in June 1973 by a team of two SAGA officers revealed that the OLI was at least as consistent in representing the weapons effects of modern weapons as any other current MOE these officers had encountered.

Minor refinements have been made in methodology to adapt to the modern arsenal. For instance:

a. Six instead of four weapons categories have been used to calculate Force Strength--adding AT and AA.

b. The mobility and vulnerability formulae have been modified to take into account such things as helicopters and APCs.

The Analysis

In a preliminary effort to use the QJMA for assessment of current force capabilities, the basic approach was as follows:

1. Using the revised OLI techniques, and obtaining data from various unclassified sources, basic OLI lists of proving ground values were prepared for NATO and Pact forces;

2. From these lists ideal, or "proving ground" division firepower inventory values were compiled for NATO divisions, and for "type" Pact divisions.

3. Both the "proving ground" combat effectiveness and the mobility characteristics of these divisions were compared.

Figure VI. WEAPONS CHARACTERISTICS CONSIDERED

Towed or Carried Weapons
- Rate of Fire
- Potential Targets Per Round (Power or Area of Burst)
- Range (or Muzzle Velocity)
- Accuracy
- Reliability
- Effect of Electronic Guidance for Missiles and Rockets*
- Effect of Self-propelled Mobility

Additional, Mobile Fighting Machines
- Battlefield Mobility (related to Speed)
- Radius of Action, or Endurance
- Protection, or Punishment-absorbing Capability
- Rapidity of Fire Responsiveness*
- Fire Control Effectiveness*
- Ammunition Supply for Main Armament*

Aditional, For Special Weapons
- Amphibious Capability*
- Helicopter Vulnerability*
- Target Availability for AA and AT Weapons*

*New

4. The divisions, individually and combined in corps and armies, were matched in hypothetical combat situations, with arbitrary but nonetheless realistic values for variations in terrain and weather.

Figure VII contains the calculated OLI values for sample American weapons known to be in the hands of units in Europe today.[9] Again it should be noted that these are proving ground values; the actual quantitative effect of these weapons upon an engagement in Europe will vary widely from one situation to another, depending upon such variables as terrain, weather, and the interaction of air support with ground weapons. A refinement has been made in the calculation of the battlefield value of an armored vehicle. Even when the environmental and operational circumstances severely restrict the armored mobility value of a tank, it still retains some value as an indirect fire self-propelled artillery weapon.

Figure VIII gives the comparable OLI values for sample Soviet weapons now known to be deployed in eastern Europe.[9]

[9]Calculated from open sources.

Figure VII. SAMPLE US WEAPONS* PROVING GROUND VALUES

	OLI
Rifle, M-16, 5.56 mm	0.2
Machine gun, M-66, .30 cal.	1.0
Machine gun, M-2	1.7
Mortar, 81 mm, M-125, SP	82
Mortar, 4.2", M-106, SP	195
RR, 90 mm	79
RR, 106 mm	112
LAW	62
TOW, SP	176
Howitzer, 155 mm, SP	189
Howitzer, 8", SP	199
Missile, Chaparral	158
AA Gun, SP, 20 mm, Vulcan	86
Rocket, Honest John (HE)	128
Tank, M-60A1	782
ARV, M-551	781
Helicopter AH-IC	509

*Sources, US FM 101-10-1, July 1971; Jane's Weapons Systems, 1973-1974

Figure VIII. SAMPLE SOVIET WEAPONS PROVING GROUND VALUES

	OLI
Rifle, AK-47, 7.62 mm	0.2
Machine gun, RPK 7.62	1.0
AAMG ZPU-4, 14.5 mm	35
AA Gun ZSU-23-4, 23 mm	148
Grenade Launcher, ATRPG-7	19
ATGM-AT-3, Sagger	157
Gun AT, M-55, 100mm	192
Mortar, 120 mm	208
RL, 122 mm, BM-21	467
Howitzer, 122 mm, M-1938	159
Gun-Howitzer, 152 mm, D-20	188
SCUD, SSM	159
GRAIL, SAM	62
SAM, SA-4, TEL	328
Tank, Med, T-54	403
Tank, Med, T-55	434
Tank, Med, T-62	570
Tank, Lt,, PT-76	173

Figure IX compares the ideal, or proving ground combat effectiveness of two US and two Soviet "type" divisions.[10] In the first column of figures is a summation of the proving ground values of these "type" divisions. The next column shows a mobility value for each division, calculated by the QJM mobility formula, under ideal movement conditions; note the high value of the Soviet tank division. The next column shows the OLI firepower value per man for each division.

Figure IX. PROVING GROUND COMPARISON, US AND SOVIET "TYPE" DIVISIONS

	Weapons Inventory		Mobility		
	OLI	Normalized	Factor	Normalized	Firepower/Man
US					
Armored Div	369,188	2.08 (1)	21.20	1.65 (2)	21.89 (2)
Mechanized Div	304,162	1.71 (2)	16.83	1.31 (3)	18.37 (3)
Soviet					
Tank Div	263,554	1.48 (3)	26.25	2.05 (1)	31.32 (1)
Mtrzd Rifle Div	177,568	1.00 (4)	12.83	1.00 (4)	16.94 (4)

The analysis considered more than 45 different hypothetical combat situations, in different kinds of terrain and weather, and with different combinations of attacking and defending forces. Figure X shows a summary of the results of seven of these, four with the NATO force on the defense, three with a NATO counterattack. In each of these examples the attacking force would be expected to be successful in good weather, based on the P_f/P_e ratio. Note, however, the effect of rainy weather upon the relative combat characteristics of the opponents. In six cases the anticipated outcome was changed, with a defender success likely. In the other case there was a reduction in the attacker's margin of superiority. Note, also, how the defender's capability is increased by the availability of a river line on which to base the defense.

Sensitivity to Terrain and Weather

Figure XI demonstrates how terrain and weather can degrade the attacker's weapons, and enhance the value of the defender's weapons. It also shows how both terrain and weather will degrade the effectiveness of armored fighting vehicles, on both offense and defense. The

[10] Calculated from open sources.

Figure X. PROJECTED OUTCOMES, SAMPLE ENGAGEMENTS

US Force	Posture	Soviet Force*	Posture	Good Weather P_f/P_e	Moderate Rain P_f/P_e	Good Weather River Crossing P_f/P_e
South Germany						
Armored Div	PD	Tank Army (1)	A	0.75	0.96**	0.82
Armored Div	PD	Tank Corps	A	0.88	1.07**	1.04**
Mchnzd Div	A	Mtzd Rifle Div	HD	1.02	0.72**	0.92**
Corps (AD, MD)	A	Tank Army (1)	HD	1.30	1.02**	1.18
North Germany						
Mchnzd Div	PD	Comb Arms Army	A	0.64	0.75	0.70
Corps (AD, MD)	PD	Tank Army (2)	A	0.94	1.13**	1.02**
Mchnzd Div	A	Mtzd Rifle Div	HD	1.36	0.97**	1.24

*Tank Army (1): 3 Tank Divisions, 1 Motorized Rifle Division
Tank Army (2): 3 Tank Divisions, 2 Motorized Rifle Divisions
Tank Corps: 3 Tank Divisions
Combined Arms Army: 1 Tank Division, 3 Motorized Rifle Divisions

**Change in predicted outcome.

top line shows the proving ground values of five selected weapons for each side: one anti-tank missile weapon, one AA weapon, one medium artillery weapon, and two different kinds of tanks.[11] Note the effectiveness of artillery in bad weather in rugged terrain, for both offense and defense. And note how, on the defense, in bad weather in rugged terrain, the "Sagger" is apparently more valuable than the T-54 and T-55, and the "Tow" apparently more valuable than the M-60 tank, and the "Sheridan."

These figures demonstrate that modern, mobile, armored and mechanized forces are extremely sensitive to variations in terrain and weather. This sensitivity reflects the effects of variables derived from World War II analysis, and is consistent with World War II, and earlier, historical experience. Its effects do not appear to have been clearly recognized up this time, however.

[11]Calculated from open sources.

Figure XI. EFFECTS OF VARIABLES ON SOVIET AND US WEAPONS

	AT-3* Sagger (Portable)	SAM SA-4	Gun How 152mm	Tank T-55	Tank T-62	AT Wpn TOW	AA Wpn Chaparral	How 155mm	Tank M60-A1	ARV M-551
Proving Ground Values	157	328	188	434	570	176	158	189	782	781
Offensive Values										
Flat Terrain, Sunshine	141	328	188	391	513	157	158	189	704	703
Rugged Terrain, Sunshine	110	262	150	130	171	123	126	151	255	234
Flat Terrain, Moderate, Rain	99	295	169	136	180	111	142	170	247	246
Rugged Terrain, Moderate, Rain	77	234	135	77**	91**	86	113	136	129**	119**
Defensive Values										
Flat Terrain, Sunshine	233	541	310	645	846	261	261	312	1161	1160
Rugged Terrain, Sunshine	239	571	327	215	282	268	275	329	384	387
Flat Terrain, Moderate, Rain	233	541	310	322	424	261	261	312	581	580
Rugged Terrain, Moderate, Rain	239	571	327	126**	182**	268	275	329	225	225

*Sagger on BMP: 274.

**Used as artillery.

Conclusion

In evaluating these figures, it must be remembered that this is a static model, and at present can be applied only to assessing the probable outcome of an engagement between two forces in contact. It does not pretend to any dynamic predictions of how these forces came in contact, or how the results which it assesses will affect the future actions and interactions of the opponents.

The issue, then, is: How reliable are the assessments of the QJM in comparison with those of any other existing available model, dynamic or static? Critics have asked this question: How can a model which is an extrapolation from historical experience possibly be as reliable in assessing current combat effectiveness and future engagement outcomes as can one which is designed to represent the results of current test and evaluation of modern weapons and equipment in a modern combat environment?

The question is doubly misleading, and demonstrates not only a lack of understanding of the characteristics of the QJM, but also misapprehension as to the capabilities of other models now in use. In the first place, the tentative OLI calculations for modern weapons are at least as soundly based upon modern weapons evaluations as are those of any other division- or theater-level model, or method of calculating weapons effectiveness in current military simulations; this was demonstrated a year ago by the SAGA study already mentioned. With the contributions of technical weapons specialists, the OLIs should be still further improved. Furthermore, because of its ability to represent combat variables, the QJM should be superior in its assessments of hypothetical combat outcomes to any other current simulation, even if one were to substitute for the OLI in the QJM formula the firepower scores, or WEIs, or WUVs, or what have you, of other simulations.

The question should therefore be rephrased: Assuming that there is no valid basis for determining the superiority of representation of weapons effects in two different models, how can the one which is based upon untested and unproven assumptions, applied to theoretical mathematical formulae which ignore many of the variables of combat, be as reliable as a model which represents the interaction of weapons with each other and with all identifiable variables of combat in a manner consistent with the actuarial results of historical experience?

The general conclusion, then, is that, no matter what may be done in the improvement of modern models, and regardless of their programs and methods for dynamic representation, realism in simulation of outcomes of hypothetical future combat is possible only by applying relevant empirical, historical experience to modern combat conditions; at present this is possible only with the QJMA.

Tactical Warfare Simulation Program II

(TWSP-II)

DESCRIPTION OF THE TACTICAL WARFARE SIMULATION PROGRAM-II(TWSP-II)

SUMMARY

TWSP-II is a deterministic, sequence-of-event simulation of ground combat. It is designed to treat the interaction of military units of company size or larger, with the terrain. Its current version will handle up to 100 combat units distributed among 20 types on each side and 50 terrain features of 10 types.

Movement and combat are assumed to take place on a two-dimensional plane. Combat losses are taken to be proportional to the enemy's strength and pre-specified killing rate. The attrition suffered by a unit during combat is computed on the basis of two principles:

- A combat unit divides its fire equally among all its opponents, and
- the attrition suffered by a unit is based on the fire it receives from all its opponents.

The combat units are divided into the two groups:

- Offensive units, which attempt to move along pre-planned routes, and
- Defensive units, which oppose the movement.

The offensive units may be scheduled to start their movements at any time and may move singly or in groups. The defensive units may be constrained to remain in position or may be allowed to retreat, either singly or in groups. Units may be scheduled to change types at any path point. At any time defensive units may be activated or de-activated.

All tactical movements- forward offensive movement, holding at specified points, defense retreats- are pre-planned by the analyst. Therefore, one "run" of the program may cover only that time period during which no new tactical decisions are are made. However, sequential runs permit the program to be used like traditional hand-played war games which involve human decisions at crucial stages.

INTRODUCTION

The first version of the Tactical Warfare Simulation Program (TWSP-I) was developed during 1963-66 by W. Fain, J. Fain, and H. Karr at the Douglas Aircraft Company (Long Beach, California). It was written in SIMSCRIPT, a simulation language developed at the Rand Corporation. TWSP-II is a FORTRAN version of the program based on the original ground warfare model. This paper is a description of the TWSP-II model.

Users of the TWSP models include Douglas, the Center for Naval Analyses, United Aircraft, and the Directorate of Land and Air Operations Research of the Canadian Department of Defense.

THE TWSP ELEMENTS

The principal elements of the TWSP model are military units, described by properties such as size, strength, location, velocity, and their ability to cause attrition ot the enemy forces, and the terrain features, described in part by size, location, concealment afforded to the combat units and the velocity changes effected.

Events which can change the properties of a TWSP element are:

- Entering or leaving a terrain feature,
- Engaging or disengaging an opposing unit in combat,
- Committing a unit to combat,
- Removal of a unit from combat, and
- Arrival of a unit at its objective.

THE TWSP MILITARY UNITS

The military units are divided into 2 groups: offensive and defensive. During the period of combat simulated by one "run" (i.e., one set of tactical plans) these roles do not change. The offensive forces remain on the "offensive"; the defensive forces, on the "defensive".

The selected level of the military units is arbitrary within limits. Since the strength loss by a unit during combat is treated as a deterministic process, the units should not be so small that random acts by individuals can be a determining factor. However, choosing units too large may obscure the effects of tactics and the interaction with terrain. Experience suggests that the program is best suited for studying military operations in which the units are from company to regimental level. Several different-level units may be entered into the same run if the element and interaction properties take this into account.

Each offensive unit is given an attack route defined by path points and an initial commitment time. At its commitment time each offensive unit will begin to move, engaging in combat the defensive units which overlap its path.

A defensive unit may be stationary and remain in position under even the heaviest fire, or given a point, or set of points, to which it retreats if the fire becomes greater than a pre-set value or if an offensive unit crosses into a specified defense zone.

To summarize the major differences between the offensive and defensive units: the offensive units are primarily moving units (although they may be halted under certain conditions), while the defensive units are essentially stationary units (although they may move under certain conditions). In general, the offensive units attempt always to move forward along their assigned paths, while the defensive units' only movements are retreats to pre-assigned positions. This is, at least, the expected use of the program. Since the path points may be located anywhere, it is possible for an offensive unit to "advance" back to its home base on the completion of a mission, and for a defensive unit to "retreat" forward.

The properties which describe the military units are listed in table I. Values of these properties are stored for each individual unit and are available at any time during the simulation. The more important properties are selected for periodic reporting.

THE TWSP TERRAIN

Like the military units in traditional war games, the TWSP units are assumed to move and to engage in combat over a two-dimensional plane described by X-Y coordinates chosen to represent a particular situation. The type of terrain covering the greatest part of the combat area is defined as "basic terrain", and the basic movement and attrition rates are given for units operating in this terrain type. A "terrain feature" is any area in which the movement and attrition rates

TABLE I

TWSP ELEMENT PROPERTIES

Military units

- Name
- Type
- Offensive phase-line group (or defensive retreat group)
- Current strength
- Total current attrition
- Current attrition from supporting fire
- Current location
- Current velocity (offensive units only)
- Support assignment
- Current number of close combat opponents
- Current number of engagements supported
- Set of units with which it is engaged

Military unit types

- Day/night basic terrain velocities (offensive units only)
- Size
- Breaking point
- Retreat attrition limit and retreat penalty factor (defensive units only)
- Support and close combat attrition factors
- Combat velocity modification factors

Terrain features

- Name
- Type
- Location and orientation
- Size
- Offensive velocity and attrition modification factors

are different from the values in basic terrain. Thus, the role of terrain features in the simulation is:

- to modify the velocity of an offensive unit, and
- to furnish concealment to an offensive unit (i.e., to modify the attrition suffered by it during an engagement).

The terrain features of the battle area are represented by rectangles of the proper size and orientation to match the actual features found on any selected area. Figure 1 illustrates how terrain features are introduced to the program.

THE COMBAT ENGAGEMENTS

During the simulated campaign there may be hundreds of individual combat engagements. The model allows 2 engagement types:

- close combat - an engagement between 2 units in physical contact, and
- "artillery" - an engagement in which a supporting unit is firing against the close combat opponents of the units to which it is assigned.

These engagements are illustrated in figure 2. Defensive unit A and offensive unit A' are engaged in close combat. Defensive unit B is supporting A with fire directed against A'. Offensive unit B' is supporting A' with fire directed at A.

In the TWSP model close combat is the basic engagement type and will occur alone if neither side has supporting units. In this case both engaged units suffer attrition. In the "artillery" engagement only one of the opponents is receiving fire. Here the term "artillery" is meant to include all supporting fire - actual artillery, naval gunfire, tactical air support, etc. The artillery engagement may occur only during a close combat engagement. However, the effects of supporting fire without close combat may be simulated by assigning supporting units to dummy units, called "impact areas," which may have size, location, and path points, but no ability to cause attrition. When impact areas engage in close combat, all attrition comes from the supporting elements assigned to the areas. Although "impact areas" usually neither cause nor suffer close combat attrition, it is possible to simulate the effects of limitations on the supporting fire by giving the opponents the ability to cause "attrition" to the "impact areas." The "breaking" of an impact area stops the supporting fire.

The course of the conflict is followed by a periodic examination of the status of each unit as described by the current values of its more important properties. These periodic status reports include not only values but also list each unit's close combat opponents. In addition to the periodic status reports, a record of every significant action is retained on a tape which may be printed to give a complete history of the conflict.

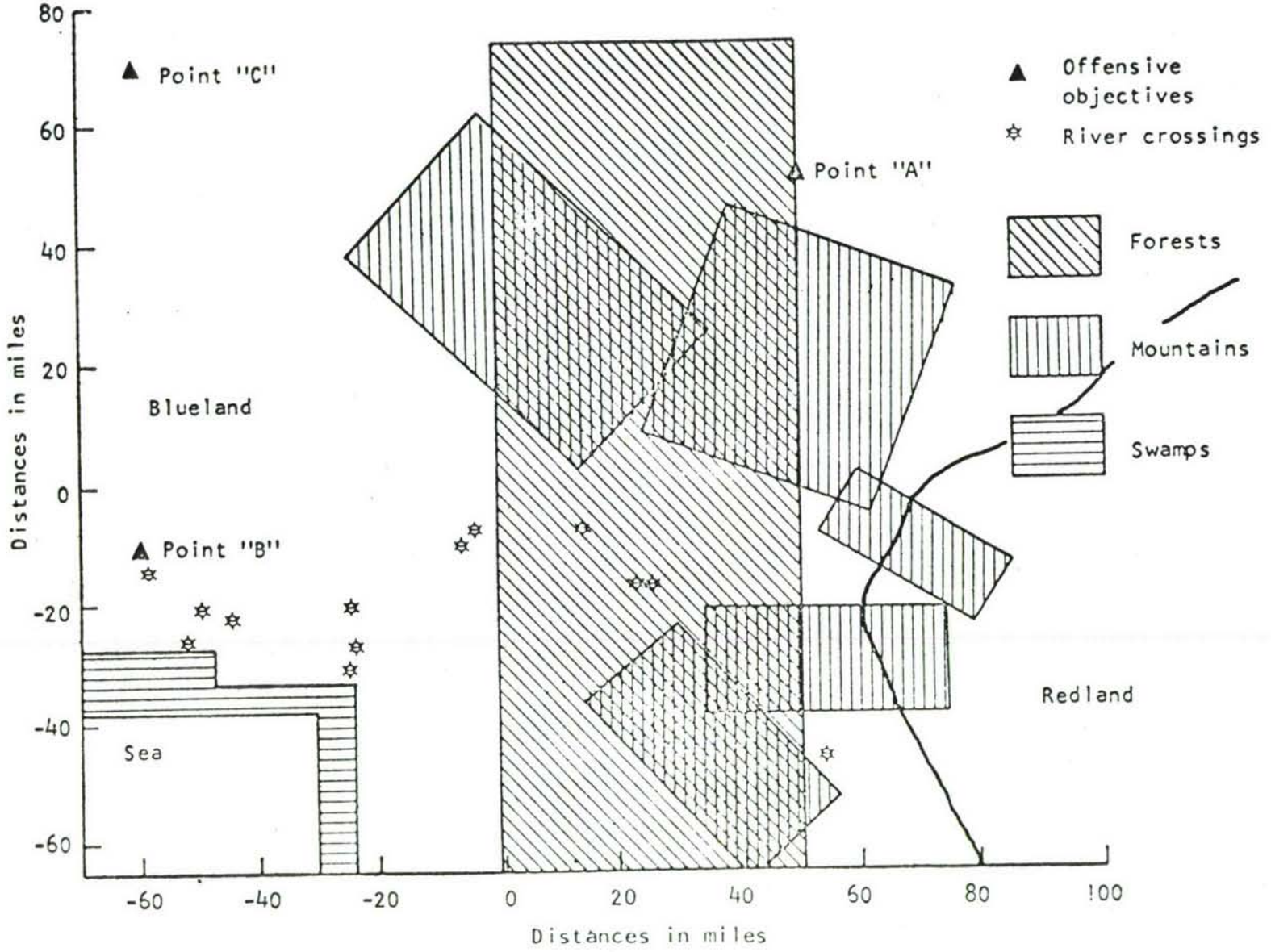
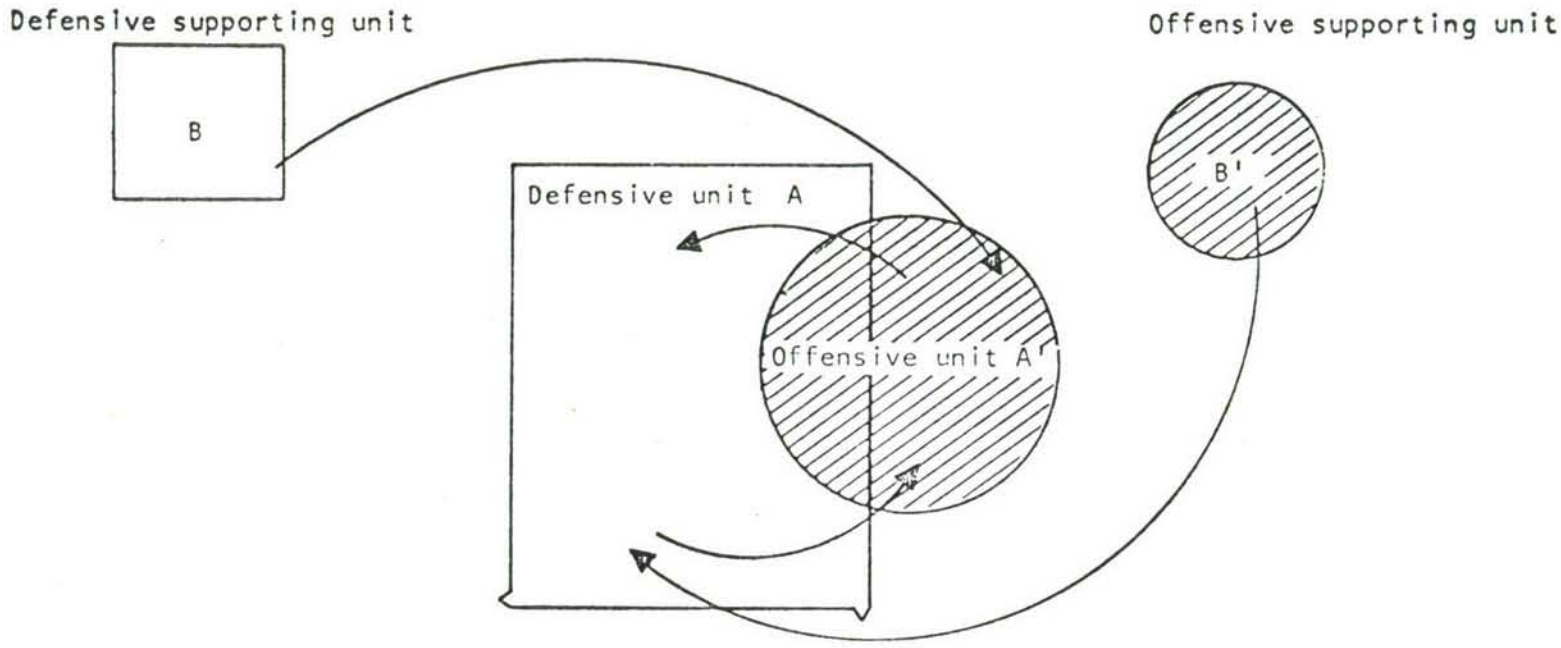


FIG. 1: IDEALIZED TERRAIN FOR COMBAT SIMULATION BY TWSP-II



Close combat: A vs. A'

"Artillery": B vs. A'
B' vs. A

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FIG. 2: THE TWO TYPES OF COMBAT ENGAGEMENTS

OFFENSIVE BATTLE PLANS

The projected route and commitment time of each offensive unit are specified by the analyst. At its commitment time, an offensive unit starts along the preplanned route toward the next path point. The unit's velocity is determined by the terrain features through which it is passing and the type and number of combat engagements.

Certain tactical maneuvers - such as maintaining orderly grouping or organizing simultaneous attacks - can be simulated by assigning units to "phase-line groups." All units so assigned will wait at path points designated as "hold" points until the surviving members of the group have arrived.

Any path point may also be designated as a type change point. Upon arriving at a type change point, the unit changes to a different type, and takes new values for certain properties. For example, a ground unit may be picked up by a helicopter at one path point and landed at the next. During the period it is airborne, it travels at the helicopter's velocity and is vulnerable to the same fire as the helicopter. Upon landing, it reverts to its original type and proceeds at its usual ground velocity.

DEFENSIVE PLANS

The type, size, and initial location of each defensive unit is program input. The defenses may be fixed or capable of retreating to pre-specified positions. There are 2 types of retreats:

- a single unit retreat - because of heavy close combat engagements, and
- a group retreat - to prevent an encirclement or an offensive breakthrough.

The single unit retreat occurs when the close combat attrition suffered by a defensive unit exceeds a limit set by the analyst. The group retreat occurs when an offensive unit crosses a "retreat line."

To simulate a wide range of defensive tactics, the terrain may be divided into defense "retreat" zones separated by "retreat lines." The crossing of one of these lines by an offensive unit causes all defensive units assigned to that retreat line to occupy their next positions. There may be many retreat groups each with its own pattern of defense zones to simulate complex retreat and hold maneuvers.

When the conditions for a retreat are encountered (heavy fire or the crossing of a retreat line), the defensive unit ceases to cause attrition. It, however, suffers a loss in strength equal to the product of its current attrition and a retreat penalty factor specified by the analyst.

COMBAT ATTRITION

During a close combat engagement both offensive and defensive units suffer and cause attrition at rates determined by their types. The strength lost by a Red unit (ΔR) during an interval of time (Δt) is calculated from:

$$\Delta R = \left(\sum_j A_j B_j / N_j\right) (\Delta t)$$

where:

B_j is the strength of the jth Blue opponent of the Red unit at the beginning of the interval

A_j is the rate of attrition caused by the Red unit's jth Blue opponent

N_j is either the number of close combat opponents of the Blue unit, or the number of engagements supported by it

Δt is the length of the time interval

The summation is over all close combat opponents of the Red unit and their supporting units. Here an "interval" is defined as that time period between events. Its length is variable, but it can never be greater than an hour.

Two ground rules are followed in assessing the attrition suffered by a unit:

- the total attrition suffered by a unit is the sum of the attrition caused by all of its close combat opponents plus their supporting units, and
- a unit spreads its fire equally over its close combat opponents.

If a unit I causes zero attrition against J, then, even though their areas overlap, J is not counted as an "opponent" of I in determining how I's fire will be divided.

FIRE SUPPORT

As indicated earlier, specified units may be assigned to provide fire support to other units to simulate artillery, tactical air support, etc. Support can be assigned either to specific geographical areas (called here "impact areas"), or directed against enemy forces during the time they are in close combat with the supported units. Such support is available to both offensive and defensive forces.

Ordinarily, the principal function of a unit will be either to engage in close combat (i.e., an infantry unit) or to provide support (i.e., artillery). However, any unit may be assigned by the analyst to support any other unit, and a supporting unit whose area overlaps an enemy unit will engage in close combat. Each type of unit is assigned attrition rates for its role in close combat and for

its role as a supporting unit. (Either rate may, of course, be set to zero.) In the model, the roles are independent, and a unit may carry on both simultaneously. Its supporting fire is spread equally over the close combat opponents of the units it supports, and its close combat fire is spread equally over its own opponents.

THE TWSP EVENTS

An event calendar is maintained by the program. All events scheduled to happen are placed in the calendar. Unless an event is cancelled or re-scheduled, it will occur when simulated time reaches its scheduled time. The TWSP events and the action which results from each are listed below:

First movement by an offensive unit

The time of the initial commitment of each offensive unit is specified by the analyst. At this time the unit is entered into the simulation and begins its movement along the first leg path. All engagements and all encounters with terrain on this first leg are determined and stored; the first engagement encounter is scheduled as an event.

Engagement and disengagement

These events modify both the attrition suffered by both units and the velocity of the offensive unit. If fire support is available to either unit, it is allocated according to the specified assignment. The time and type of the next event involving the offensive unit are determined, and the event is scheduled. The possibility of a defensive unit's collapse or retreat is investigated and, if necessary, scheduled. For a disengagement, events are re-scheduled as necessary.

Encounter with or departure from a terrain feature

Either event will modify the velocity of the offensive unit. If the unit is simultaneously engaged in close combat, then its current attrition may be modified if the terrain feature offers concealment. The next event involving the unit is determined and scheduled.

Arrival at the end of a leg

When the offensive unit has reached the end of a leg, it will normally start along the next leg. This is similar to a first movement event.

Wait by an offensive unit

Upon reaching a path point specified as a hold point, an offensive unit waits for the surviving members of the phase-line group to arrive at their hold points. Any combat engagement in progress will continue, but no movements are scheduled.

Offensive type change

The type of an offensive unit may be changed at any of its path points. Upon arriving at a path point designated as a type-change point, the unit immediately takes on the properties of its new type.

Proceeding of a phase-line group

When all surviving units of a phase-line group have reached their respective hold points, the entire group proceeds. This is similar to a first movement event.

Breaking of a unit

This event occurs when the strength of either an offensive or a defensive unit has dropped below a pre-selected "breaking point." The unit is considered to be ineffective as a combat unit and is removed from action (breaks). At this time all of the units with which it was engaged are released, their movement and attrition rates are recalculated, and their next events re-scheduled or cancelled as required.

Retreats

As discussed earlier, 2 types of defensive retreat are possible - single unit and group retreats. The single-unit retreat occurs when the close combat attrition against the defense rises above a pre-selected level; the group retreat is initiated by the movement of an offensive unit into a retreat zone. There is no limitation on the specification of retreat lines and groups except those dictated by logic; i.e., there must be at least one retreat line per retreat group, and a unit may belong to only one retreat group.

Arrival at the final path point

Upon arriving at its final path point, an offensive unit halts. Unless it is currently engaged or becomes engaged with defenses arriving there later, this unit takes no further part in the simulation. When all surviving offensive forces have reached their objectives, the simulation is effectively over.

Arrival or removal of a defensive unit or terrain feature

New defensive units and terrain features may be introduced into the simulation at any time after the start; old defenses and terrain features may be removed at any time. These arrivals and removals are exogenous; i.e., their times are pre-specified by the analyst.

Defensive unit type changes

A defensive unit may change types either at a pre-specified time or at any of its retreat positions. When a defensive position has been specified as a type-change point, several parameter changes may occur. The program processes these changes in this order:

1. Conditions for a retreat are encountered.
2. If the unit has no retreat position to which it can go, then it must re-

main engaged in this position, and the program goes on to the next EVENT. If the unit has another position to which it can retreat, a loss in strength penalty is applied.

3. If this penalty causes the unit strength to drop below the breaking point, then the unit "breaks" and is removed from the simulation.

4. If the unit has not "broken," it is moved to its next position.

5. If this position is designated as a type-change point, the unit assumes its new type.

6. If its current strength is now below the breaking point of the new type, the unit breaks.

7. If the current attrition is now above the retreat limit, the unit retreats again, if it has a place to go.

The program repeats steps 1-7 until the unit has broken, or reached its last position, or arrived at a place where its attrition is below its retreat limit.

With an understanding of the order of operations carried out by the program, the analyst can control to some degree the events of the simulation by his choices of unit types and type-change points.

End of the simulation

The simulation ends (i.e., no more output is written and the computer program stops) at a time specified by the analyst. It may or may not match the arrival of the last unit at its objective.

THE TWSP INPUT

A general list of the properties which describe the TWSP in military units was given in table I. Some of these properties are input numbers assigned by the analyst; the rest are calculated by the program as the simulation proceeds. This section will list and describe those properties required as input.

Certain of the properties of the military units are common to a number of individual units. It is more convenient to assign values to these properties by unit type and to identify each individual unit as a particular type. Thus, a number of properties can be transferred to a unit without repeating them in the data deck.

Offensive types

Offensive unit characteristics which are specified by type are:

- Unimpeded velocity in the basic terrain for day and night operations. Each 24-hour period is divided into two 12-hour periods. Which 12 hours is considered "day" is specified by the analyst; usually from 0700 to 1900 hours.

• Radius of action. An offensive unit is assumed to cover a circular ground area. This is not necessarily the area physically occupied by it, but the area over which the unit will engage in close combat with defenses whose areas overlap its own. In figure 3 unit A is engaged with B during the period from the time of first contact at P_0 to the time of the last contact at P_1. The lengths of the close combat engagements can, therefore, be controlled in part by the choice of the radius of action.

• Breaking point. This is the strength which a unit ceases to be an effective military force and is removed from the simulation. A "broken" unit may not be re-entered into the simulation.

A unit may obtain new values for these parameters by changing to a new tape.

Defensive types

Defense properties specified by type are:

• Half-widths in the X- and Y- directions.

• Breaking point. This is the strength which a unit ceases to be an effective military force and is removed from the simulation. A "broken" unit may not be re-entered into the simulation.

• Attrition rate at which the unit will disengage and retreat.

• Retreat penalty factor. This is the factor by which a unit's current attrition is multiplied to give the strength loss penalty assessed against that unit for a retreat.

The following properties depend on both the offensive and the defensive types:

• Attrition rates, for both close combat and supporting fire.

• Factors by which the offensive unit velocities are modified (either increased or decreased) by engagements with defenses.

None of the individual properties of the terrain features are grouped by type. However, the 2 parameters which control the interaction of offensive units with terrain features are specified by type. These are:

• The factor by which offensive unit velocities are modified by terrain. When a unit is in several terrain features simultaneously, there is no cumulative effect. The velocity is determined by the terrain feature which causes the greatest reduction.

• The factors by which the attrition suffered by an offensive unit is modified by terrain. This concealment effect is cumulative; the attrition is multiplied by the factor for each terrain feature the unit overlaps.

In addition to the information which can be supplied about a number of units simultaneously through the device of unit "types," certain data must be given specifically for each unit.

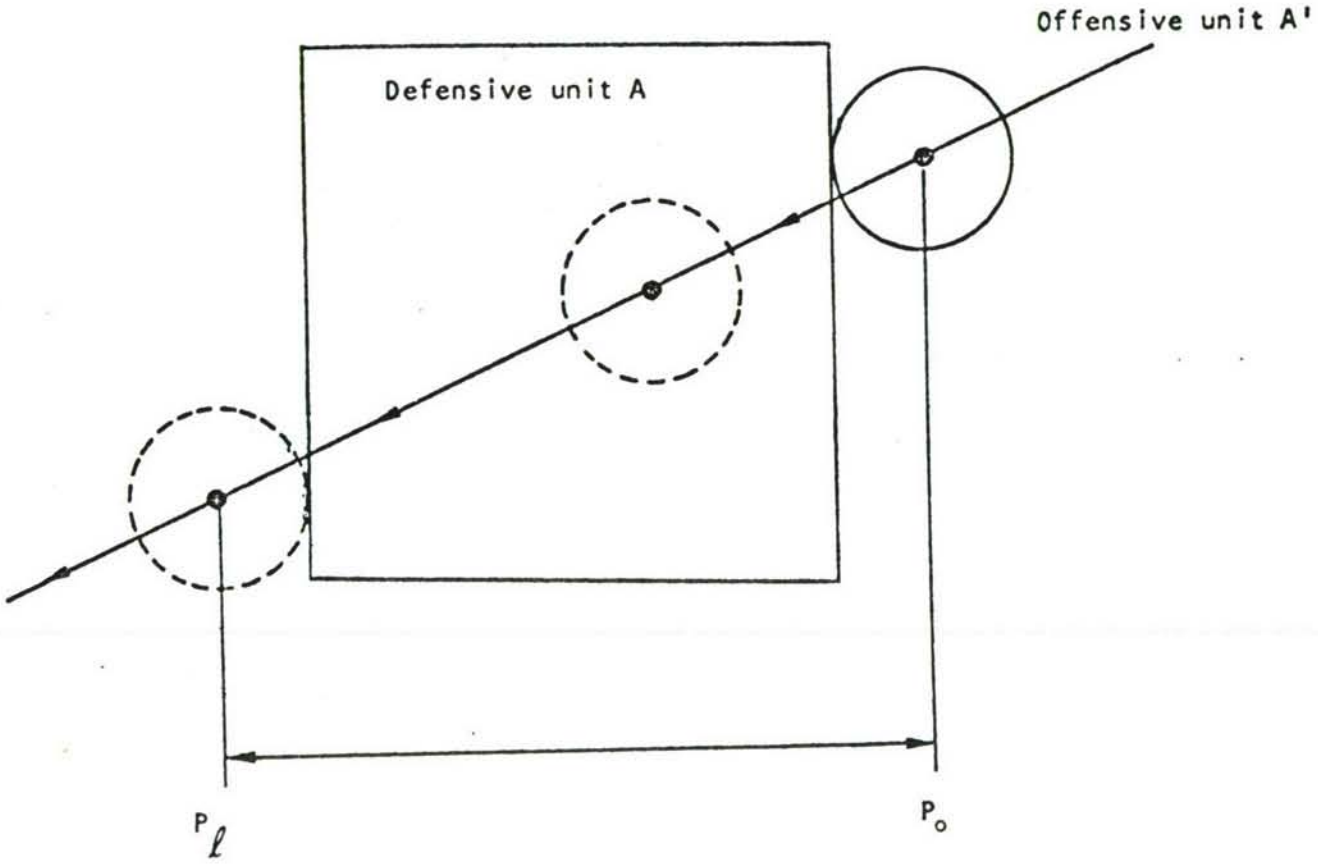


FIG. 3: PERIOD OF CLOSE COMBAT ENGAGEMENT BETWEEN UNITS A AND A'

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Offensive units

The following information must be supplied for each offensive unit:

- Name. This is an identification code for the unit of up to 8 alpha-numeric characters. Examples might be: "RINFO6" (the 6th Red Infantry battalion) or "MINF A12" (the "A" company of the First Marine infantry battalion of the 2nd regiment).

- Unit type. This is an integer identifying the type. The unit will have the parameter values for size, breaking point, and velocities which were specified for this type.

- Time of first movement. This is the time at which the unit starts along its path. Further movement is determined by the unit's velocity and engagement status.

- Fraction by which initial strength of the unit is reduced from 1.0.

- Group identification number. This is an integer which identifies the phase-line group to which this unit belongs. There is a limit of 25 groups, but there is no limit on the number of units assigned to any one group, or on the number of hold points given to any one group. The only requirement is the logical one that all members of a group be given the same number of hold points. Violating this rule would prevent some units from completing their paths (and could therefore be used as a device for altering offensive tactics from run-to-run without extensive data changes).

- Path points. The complete path which the offensive unit will follow (unless halted by defense action) is specified. A unit may have any number of path points as long as the total number of points for all offensive units is not greater than 800. Any of the path points may be specified as "hold" points; there is no requirement that the hold points be physically located together.

- Support assignments. These are the units to which this unit will give supporting fire. It is the analyst's responsibility to plan the velocities and paths so that the supporting unit is always within range.

Defensive units

The following information must be supplied for each defensive unit:

- Name. Like the offensive unit name, this is an 8-character identification code.

- Unit type. This is an integer specifying the type. The unit will have the size, breaking point, etc., specified for this type.

- Retreat - group identification number. When an offensive unit enters a pre-specified retreat zone, the group of defenses assigned to (but not necessarily physically located within) that zone will retreat. The number of such groups and the number of units assigned to any one group are unlimited. (A defense "zone" is defense of "type" 30. In this case, "30" does not designate a military type, but is rather a code used by the program to identify a "zone". Defense parameters such as strength, current attrition, breaking point, etc., have no meaning for a retreat zone.)

- Fraction by which the initial strength is reduced from 1.0.

- Defense positions. The set of positions which may be occupied in turn by this defense are specified by the analyst. For each position there must be given the X- and Y- coordinates, the rotation angle, (measured as shown in figure 4) and a code which indicates whether the point is an intermediate position or the final position and whether or not a type change is to take place there.

- Support assignments. These are the units for which this unit will provide supporting fire.

Terrain features

Information required for each terrain feature is:

- Name. This is an identification code of up to 8 characters.

- Type. This is an integer identifying the type of terrain. Although no parameters belonging to the individual terrain features are specified by type, the factors controlling the interaction of terrain and offensive units are dependent on types.

- X-Y coordinates of the center location.

- Half-widths in the X and Y directions.

- Angle of rotation. This angle is measured as shown in figure 4.

THE TWSP OUTPUT:

THE PERIODIC STATUS REPORTS

The progress of the simulation is monitored by periodic reports which give the current status of all units. An example of the output is shown in appendix D. The time interval between reports is specified by the analyst; in this example, it is one hour. Thus, the report for period one gives the status of the units at day 0, 12 hours, and 0 minutes. *

The report is divided into 2 similar sections - a summary of offensive forces and a summary of defensive forces. The following information is given:

- Unit name.

*The basic time unit of the simulation is a "day", and all variables like start times and velocities are expressed in that unit. However, when "time" is written as part of the output, it is always expressed in days, hours, and minutes.

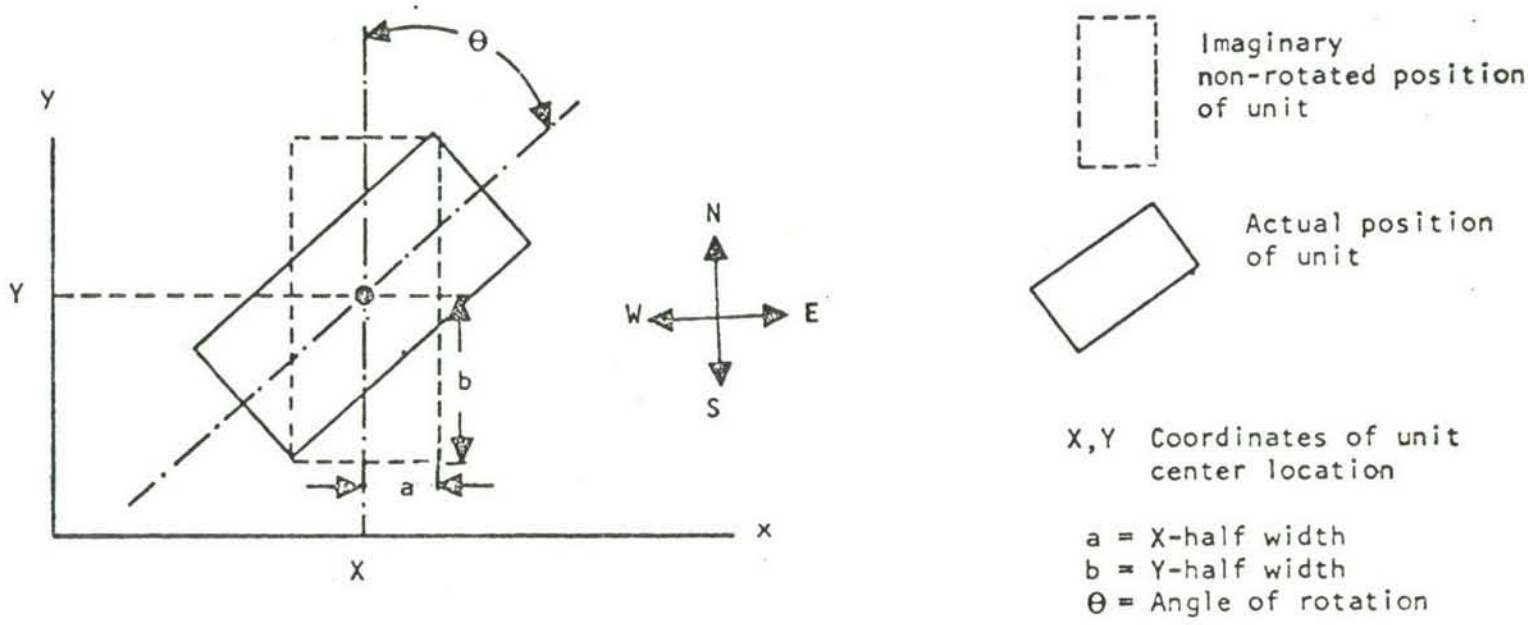


FIG. 4: HALF-WIDTHS AND ROTATION ANGLE FOR A DEFENSE OR A TERRAIN FEATURE

- Unit type.

- Status code: a "1" signifies that the unit is currently active or will become active later; a "0" indicates that the unit has been removed from the simulation.

- Current strength. This is the fraction of a full-strength unit remaining. (For a "retreat line," (i.e., "defense" of type 30) strength has no meaning and this entry should be ignored.))

- X- and Y- coordinates of the unit's current location. These values will be given in the units of distance chosen by the analyst. Since they are set to zero for broken units, the final location of a broken unit must be obtained from the history reports discussed below.

- Distance from the unit's current location to its final path point (for offensive units only).

- Current attrition rate. Two numbers are given. The top number is the total current attrition suffered by this unit; the second is the attrition due to the enemy's supporting units (artillery, naval guns, air support, etc.). These rates are expressed as fractions of a full unit lost per 24-combat-hours.

- Current velocity of the unit (for offensive units only). Velocities are expressed in units of distance covered per 24 hours.

- Names and types of all opponents with which the unit is engaged. For an offensive unit, the terrain features it currently occupies are also listed.

At the end of the list of individual units, there is summarized by type some information concerning the total remaining strength, the number and type of surviving active units, and for offensive units, the average remaining distance to the path end.

THE COMPLETE HISTORY

In addition to the periodic status reports, a record of every significant event is retained on tape. At the end of the simulation the analyst can specify that this tape, which gives a complete history of the simulation, be printed.

From the periodic reports and the event history, a complete picture of the simulated combat can be obtained.

TITLE: IDAGAM I - IDA Ground Air Model I

PROPONENT: OJCS (SAGA/GPFD)

DEVELOPER: Institute for Defense Analysis (IDA)

PURPOSE: IDAGAM I is used in theater-level force structure studies of ground and air conventional conflict. For movement and overall attrition calculations, IDAGAM does not use firepower scores, rather a choice to include an antipotential potential method to calculate the value of a weapon, based on that weapon's capability to destroy the value of the opposing weapons. Attrition by weapon type, is calculated using the opposing weapons densities, capabilities and allocation of fire.

GENERAL DESCRIPTION: IDAGAM I is a deterministic, model of a conventional theater-level air and ground combat between two opposing forces. The geographical structure of the model consists of a series of nonintersecting sector, each sector consisting of intervals, each of which have a type terrain and posture assigned to them by the user. A region consists of one or more sectors at a specified distance from the FEBA and there is a communication zone for each side located to the rear of the regions.

The model currently plays the following resources. It may however be recompiled to alter these dimensions.

1. People-three categories: combat, combat support and service support.

2. Weapons-up to 12 types including SAMs and AAA's.

3. Divisions-up, to six types.

4. Supplies-the model plays only one type measured in tons.

5. Aircraft-up to 10 types.

6. Airbases-two national airbases in each region and one notional airbase in the communications zone, thus the model considers airbases at three different ranges from the FEBA.

7. Aircraft Shelters-one type in fixed locations.

8. Aircraft Mission-consisting of up to seven primary and five secondary missions.

9. Air Munitions-up to 9 types loaded on notional aircraft for delivery on close air support missions.

IDAGAM is a fixed time-step model usually in days. The user may add, delete, and/or change forces or parameters at the beginning of specified time periods.

The user has a choice from among eight attrition equations for the air-model interaction including binomial, exponential and Lanchester and among several methods of computing ground capability.

INPUT: The model needs some 600 input variables and arrays. Each input data card is uniquely identified for input into a base case set of data.

OUTPUT: All output is in the form of computer printouts of user selected summaries.

1. Detailed Report (Used for debugging)

2. Daily Selected Summary Tables

3. Selected Summary Report (1 page)

MODEL LIMITATIONS: IDAGAM does not simulate a breakthrough type situation. Logistic aspects of the model are very aggregated. Model is expected value vice Monte Carlo which could be argued to be a limitation.

HARDWARE: HIS 6080

SOFTWARE: FORTRAN Y - ~~HIS~~

TIME REQUIREMENTS: Six CPU minutes per 15 day game.

SECURITY CLASSIFICATION: UNCLASSIFIED

FREQUENCY OF USE: 150 - 200 times per year

POINT OF CONTACT: General Purpose Forces Division (GPFD)
Studies, Analysis, and Gaming Agency (SAGA)
Office of the Joint Chiefs of Staff (OJCS)
The Pentagon, Washington, D.C. 20301
Telephone: OX5-9003

USER: SAGA(OJCS)

KEYWORD LISTING: Ground Air; Deterministic Computer Model; Theater-level; Conventional combat

A SUMMARY OF IDA GROUND-AIR MODEL I (IDAGAM I)

Lowell Bruce Anderson
Jerome Bracken
James G. Healy
Mary J. Hutzler
Edward P. Kerlin

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INSTITUTE FOR DEFENSE ANALYSES
400 Army-Navy Drive
Arlington, Virginia 22202

June 1974

FOREWORD

IDAGAM I is a deterministic, fully automated model of nonnuclear combat between two opposing forces. This model is described in detail by

> Lowell Bruce Anderson, Jerome Bracken, James G. Healy, Mary J. Hutzler, and Edward P. Kerlin, *IDA Ground-Air Model I (IDAGAM I), Vol. 1: Comprehensive Description; Vol. 2: Definitions of Variables; Vol. 3: Detailed Description of Selected Aspects; Vol. 4: Computer Program Documentation; Vol. 5 (*SECRET*): Testing* (U), IDA Report R-199, May 1974 (Review Draft).

and

> Lowell Bruce Anderson, Debbie Bennett, and Mary J. Hutzler, *Modifications to IDAGAM I,* IDA Paper P-1034, June 1974 (Review Draft).

This paper consists of selected excerpts from Volume 1 of the first reference. Both references should be consulted for more detailed information concerning IDAGAM I.

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INTRODUCTION

IDA Ground-Air Model I (IDAGAM I) is a deterministic, fully automated model of nonnuclear combat between two opposing sides. This model is the latest in what might loosely be called a family of models that began with ATLAS (Kerlin and Cole [19]) and led first to GACAM (Bracken, et al. [12]), then to GACAM II (Bracken, et al. [11]), and then to IDAGAM I. This is a "loose" family because the only thing that really ties it together is that the developers of each succeeding model, before developing that model, looked closely at the advantages and limitations of its predecessors. These models were not developed at the same place or under the same funding; and, with the exception of Edward Kerlin, they were not developed by the same people.

ATLAS had its own forerunners, but they were not fully automated models. GACAM was developed with a goal of simplifying the ATLAS ground-combat process, so that a more elaborate air-combat process could be played and so that the total computer running time of GACAM would be small enough to allow it to be used as part of higher-level models, such as GANCAM and the World-Wide Integrating Model (Bracken, et al. [12]). This goal was accomplished, but in the process the GACAM ground-combat process was, according to some critics, too oversimplified.

This criticism led to GACAM II, which attempted to increase the level of detail of the GACAM ground process by introducing sectors, weapons by type, and other details. However, GACAM II still retained the basic firepower structure of ATLAS and GACAM. This defect was felt to be severe and led to IDAGAM I. In addition to the "omission" characteristic of not being a firepower model, we believe that IDAGAM I has many positive characteristics that make it generally preferable to its predecessors.

Chapter I

LEVEL OF DETAIL OF IDAGAM I

A. THEATER STRUCTURE

IDAGAM I is designed to be a theater-level model. If desired, only part of a theater can be played (and, with some restrictions, several theaters can be played simultaneously). For the purposes of this paper, we will assume that IDAGAM I is being played at the theater level.

1. Geographical Sectors

The theater structure of IDAGAM I contains a series of nonintersecting geographical sectors that cover the theater area of interest. These geographical sectors are considered as avenues of advance that run the length of the theater, that are not necessarily of constant width, and that are separated from adjacent sectors by rough terrain, neutral countries, or other specifics of the theater area that would hinder combat across sector boundaries. Each geographical sector is assumed to consist of a finite, but not necessarily fixed, number of intervals. Terrain-type variations, width-of-sector variations, defensive barriers, and other geographical characteristics will be played with these intervals. Intervals are assumed to be areas of constant width but variable depth, with the terrain or barrier assumed to be constant throughout the interval.

2. Combat Sectors, Regions, and COMMZ

While geographical sectors run the length of the theater, ground combat will take place only in the portion of the geographical sector that is relatively near the line that separates the two sides. (This line is traditionally called the forward edge of the battle area, or FEBA.) If a unit is in the J^{th} geographical sector and is close enough to the FEBA to participate in combat, we will say that the unit is in the J^{th} combat sector (or, simply, in the J^{th} sector). If that unit is not close enough to participate in combat (i.e., it is in reserve), then we will say that the unit is in a region or in the COMMZ (defined below).

Regions consist of the rear portion of one or more geographical sectors. The left boundary of a region is the left boundary of the leftmost geographical sector contained in that region, and the right boundary of a region is the right boundary of the rightmost geographical sector contained in that region. Which geographical sectors are contained in which regions is an input to the model.[1] The grouping of geographical sectors into regions need not be the same for both sides. Thus, since the forward part of a geographical sector is a combat sector, each region boundary must coincide with the boundary of some combat sector. But region boundaries for one side need not correspond to region boundaries for the other side.

The number of regions and sectors played in IDAGAM I is an input. The maximum number of regions and sectors that can be played is part of the computer program, but this maximum number is easily changed.

[1] However, if two geographical sectors are in a region, then all geographical sectors between them must be in the same region.

There is exactly one communications zone (COMMZ) for each side in the theater. The COMMZ for each side is located to the rear of all battle activity.

With the two opposing sides being denoted by Blue and Red, an example of theater structure with seven sectors, two Blue regions, and three Red regions is given in Figure 1.

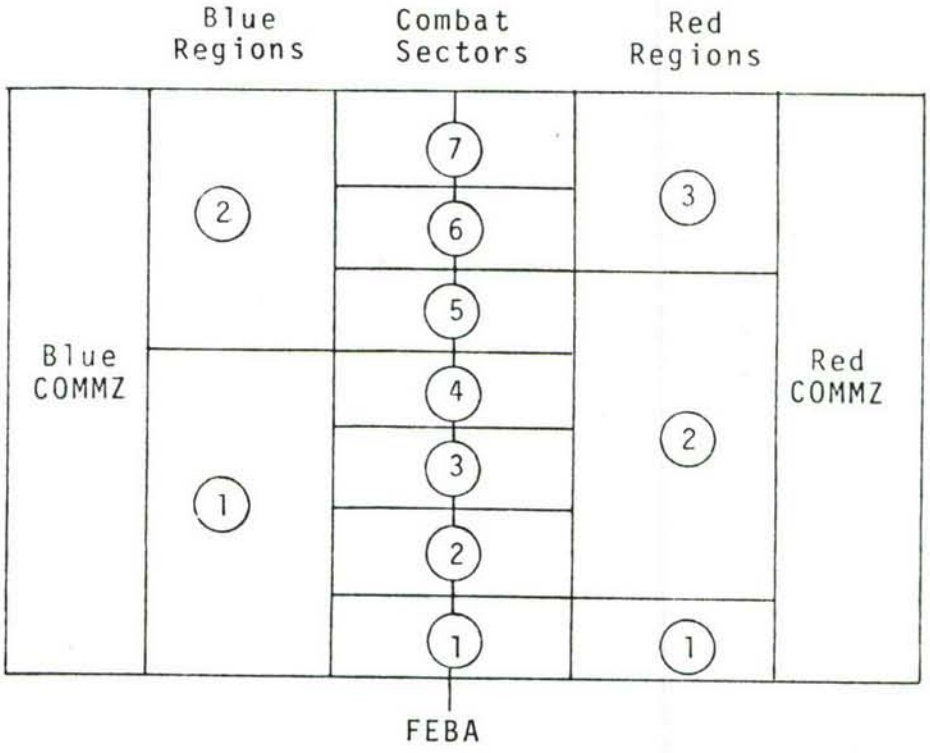


Figure 1. EXAMPLE OF THEATER STRUCTURE

B. RESOURCES

The two opposing sides, which are denoted by Blue and Red, are represented symmetrically in IDAGAM I. Each side can have ground resources and air resources.

1. Ground Resources

a. People

IDAGAM I accounts for exactly four categories of people (combat, combat support, service support, and theater support). However, the fourth category, theater-support personnel, must always be located in the COMMZ and cannot cause or suffer attrition (except for nonbattle-related casualties). They are considered only for accounting and supply-consumption purposes.

The distinction between the other three categories is also only for accounting purposes; however, the sum of the number of people in these three categories is significant in the attrition and FEBA-movement calculations. Thus, IDAGAM I actually "plays" only one type of people; and this type is the sum of the number of people in the first three personnel categories listed above.

b. Weapons

The number of types of weapons on each side that are played in IDAGAM I is an input.[1] For example, IDAGAM I could be played with 10 types of weapons on each side, where

Blue weapon type 1 = small arms;
Blue weapon type 2 = armored personnel carriers;
Blue weapon type 3 = tanks;
Blue weapon type 4 = antitank weapons;
Blue weapon type 5 = field artillery (155 mm or 8 in.);
Blue weapon type 6 = field artillery (175 mm);
Blue weapon type 7 = mortars;
Blue weapon type 8 = helicopters;

[1]The maximum number of types of weapons that can be played is fixed in the computer program but can easily be changed. As many other quantities have this property, we will not make this statement each time such a quantity is introduced.

Blue weapon type 9 = antiaircraft guns;
Blue weapon type 10 = surface-to-air missile systems;

and

Red weapon type 1 = small arms;
Red weapon type 2 = armored personnel carriers;
Red weapon type 3 = tanks;
Red weapon type 4 = antitank weapons;
Red weapon type 5 = field artillery (155 mm or 122 mm);
Red weapon type 6 = field artillery (130 mm);
Red weapon type 7 = mortars;
Red weapon type 8 = multiple rocket launchers;
Red weapon type 9 = antiaircraft guns;
Red weapon type 10 = surface-to-air missile systems.

The last type of weapon on either side must be surface-to-air missile systems (SAMs) and, if a second type of ground-to-air weapon system (such as short-range SAMs or antiaircraft guns (AAGs)) is to be played, then it must be the second-to-last type of weapon.[1] Other than this, there is no formal restriction on what types of weapons can be played; and different types can be played on each side. However, some types of weapons (e.g., nuclear weapons or biological weapons) would not be appropriately modeled by IDAGAM I.

[1] IDAGAM I allows up to two types of ground-to-air weapons to be played, and one of these types is assumed to have shorter range than the other. In this report, we assume that these two types of weapons are SAMs and AAGs. However, IDAGAM I can also be used to play two types of SAMs (long-range and short-range) if desired.

If two types of ground-to-air weapons are not played, then certain parameters must be zeroed out, so that the second-to-last type of weapon is given no ground-to-air capability and no aircraft are sent on AAG-suppression missions.

c. Minefields

Mines are not played as a type of weapon as described above. Instead, IDAGAM I plays preplanned minefields that are assumed to extend across one or more sectors and that can be of variable depth and density. Minefields affect the movement and casualty rate of the attacker until the minefield is breached. (A defense using a minefield is treated essentially as a separate type of defensive posture.)

d. Divisions

The number of types of units that are played on each side is an input. However, these units must be separate units; one cannot be a part of another. Thus, IDAGAM I can play divisions and separate brigades, or brigades and separate battalions, but it cannot simultaneously play both divisions and the brigades that compose those divisions. Subject to this restriction, a unit of any size can be played; and units of various sizes can be played simultaneously.

IDAGAM I was designed with the idea of playing notional units (i.e., a type-i unit in sector J would be indistinguishable from any other type-i unit in sector J). (Units of different types in the same sector and units of the same type in different sectors are distinguishable.) However, it is possible under some severe restrictions to use IDAGAM I to play individual units. For simplicity, throughout this paper we will assume that notional units are being played, which we will refer to as divisions.

As an example, IDAGAM I could be played with four types of notional divisions on each side, where

Blue division type 1 = U.S. armor division;
Blue division type 2 = U.S. mechanized infantry division;

Blue division type 3 = non-U.S. NATO armor division;

Blue division type 4 = non-U.S. NATO mechanized infantry division;

and

Red division type 1 = Soviet/Czech tank division;

Red division type 2 = Soviet/Czech motorized rifle division;

Red division type 3 = E. German/Polish tank division;

Red division type 4 = E. German/Polish motorized rifle division.

Each type of division has several characteristics that differentiate it from other types of divisions. For example, each type of division has its own--

(1) TOE (authorized number of people and weapons by type);

(2) actual number of people and weapons by type;

(3) effectiveness degradation function (this gives the percent degradation of effectiveness as a function of the percent strength of the division);

(4) reorganization rate;

(5) relative-movement rate;

(6) relative size;

(7) strength level at which the division is withdrawn from combat; and

(8) strength level required for the division to enter combat.

e. Location of Divisions, Weapons, and People

A divison can be located in any (combat) sector, in any of its side's regions, or in its side's COMMZ.[1] If a division is in a sector, then that division is in combat and can cause

[1]This structure gives the maximum number of possible locations for each division. Fewer locations for specific types of divisions can be played. For example, if it is desired, only U.S. divisions in certain sectors and only non-U.S. NATO divisions in other sectors can be played.

and receive casualties. If a division is in a region or the COMMZ, then it is in reserve and cannot cause casualties. Divisions in the COMMZ cannot receive casualties, but divisions in regions can be attacked by enemy aircraft.[1]

Weapons can either be in a division (and so be located wherever the division is located) or be in the weapon-replacement pool in the COMMZ (there is one such pool for each side). There can never be more weapons in a division than the TOE of that division calls for (and, of course, the TOE of a particular type of division might call for no weapons of a particular type).

The first three types of people (combat, combat support, and service support) can either be in a division or be the personnel-replacement pool in the COMMZ. However, unlike weapons, people are not distinguished by type when they are in the replacement pool. They are distinguished by type only in divisions; and when people are moved from the replacement pool to a division, they are assumed to be distributed by type according to the needs of that division.

The fourth type of people (theater support) are located in the COMMZ and cannot be either in divisions or in the personnel-replacement pool.

f. Supplies

IDAGAM I plays exactly one type of supplies, which should be considered as general supplies and should include food, ammunition, and fuel for both ground forces and air forces (they are included under ground resources for convenience only). The unit of measure for these general supplies is considered to be tons, and the model assumes that each person (by type), each

[1] IDAGAM I does not play enemy air attacks on resources in the COMMZ.

All divisions in reserve can suffer nonbattle-related casualties.

ground weapon (by type), and each aircraft (by type) consumes a certain number of tons of supply per time period (for people and ground weapons, this consumption rate is also a function of posture).

g. Surface-to-Air Missile Systems

SAMs differ from the other types of weapons in the following respects: First, as noted above, SAMs have no "ground value" and are the only weapons with no such value. (We assume that AAGs could be used against enemy ground troops.) Second, the "ammunition" for the SAMs (i.e., the actual missiles themselves) are not played as part of the general supplies but are accounted for separately.[1] Finally, both SAMs and AAGs can be used to defend airbases (as will be discussed in Subsection 2, which follows).

2. Air Resources

a. Aircraft

The number of types of aircraft on each side that are played in IDAGAM I is an input. For example, IDAGAM I could be played with seven types of Blue aircraft and three types of Red aircraft, where

---

[1] This was done because these missiles are, in a sense, weapons themselves and because the number of missiles fired is dependent not only on the number of launching systems but also on the number of enemy sorties that fly within range of these systems. Thus, the number of missiles expended per launcher is not constant; but, rather, it must be computed by the model. Given that the model has to do this computation, it seems worthwhile to keep track of the number of missiles expended.

Blue aircraft type 1 = F-4;
Blue aircraft type 2 = A-7;
Blue aircraft type 3 = F-105;
Blue aircraft type 4 = F-111;
Blue aircraft type 5 = F-100;
Blue aircraft type 6 = F-104;
Blue aircraft type 7 = F-5 or G-91;

and

Red aircraft type 1 = SU-7 or MIG-19;
Red aircraft type 2 = MIG-17 or MIG-21;
Red aircraft type 3 = MIG-23.

Parameters such as kill-effectiveness in an engagement with an enemy aircraft, effectiveness when attacking an enemy airbase, notional load of munitions (and hence effectiveness on close-air-support missions), sortie rate, range considerations, shelter priority, and occupancy factor (the percent of time that an aircraft is on the ground and so is vulnerable to an enemy air-borne attack)--these parameters are functions of type of aircraft. The input assignment of aircraft to missions is also a function of aircraft type (as will be explained in Subsection d, below).

b. Airbases

IDAGAM I plays two notional airbases in each region and one notional airbase in the COMMZ for each side. Unlike the number of types of weapons or types of aircraft, this number of notional airbases is fixed in the model and cannot easily be increased. (It would be easy to play fewer than this number of notional bases.) The rationale behind choosing this structure is as follows:

One notional airbase for each side was considered insufficient for the following reasons: First, certain aircraft may be able to fly close-air-support (CAS) missions only in certain

sectors. For example, U.S. aircraft may be able to provide support only in sectors defended by U.S. divisions; and non-U.S. NATO aircraft may only be able to provide support in sectors defended by non-U.S. NATO divisions. These restrictions are handled by playing at least one notional airbase in each region.

However, allowing only one notional airbase for each region is still insufficient. To see this, consider the following simple case: Suppose each side had only one type of aircraft, and suppose that Blue's aircraft were identical in all respects to Red's aircraft. Suppose, further, that these aircraft had a fixed range--no matter what mission they flew. Then, aircraft that are assigned to attack an enemy airbase would have to be based close enough to the FEBA to reach that enemy airbase, whereas aircraft that are assigned to provide CAS need be only close enough to reach the FEBA. The two-sided picture is as follows:



Blue aircraft could attack the Red rear airbase only from the Blue forward airbase--and only if that airbase were very near the FEBA--and vice versa. But since an airbase very near the FEBA would be subject to attack by artillery (among other things), it is not reasonable to locate an airbase there. Thus, in this simple case, if a side wanted to use its aircraft on CAS missions only, it could assign all its aircraft to its (invulnerable) rear airbase. But any aircraft that are to fly airbase-attack (ABA) missions (or be flexible enough to fly either mission)

must be stationed on the forward airbase, and these aircraft could attack only the enemy forward airbase.[1]

Of course, this case is oversimplified. Different types of aircraft have different maximum ranges, and there are range-payload trade-offs. But even in this simple case, if a model is to play both CAS and ABA missions properly, then the model should play at least two notional airbases--one forward and one rear. And if playing airbases in this way is required in the simple case, then in the more complex case, where actual ranges of the aircraft played are considered, a model would certainly be deficient if it did not play airbases at different ranges from the FEBA.

IDAGAM I can play airbases at three different ranges from the FEBA. The notional airbases closest to the FEBA are those in the forward part of the regions. The next closest are those in the rear parts of the regions. The notional airbase farthest from the FEBA is the one in the COMMZ. The forward and rear airbases in each region are meant to handle the problem described above, and the COMMZ airbase is meant to allow IDAGAM I to play long-range aircraft (like the F-111) or aircraft that could have a long range at the cost of a reduced payload.

In summary, the airbases played in IDAGAM I are notional airbases, each of which is considered to be composed of one or more actual airbases. IDAGAM I plays several notional airbases in order to allow aircraft to provide CAS in certain sectors only, and to play range considerations related to different types of missions as well as to different types of aircraft.

Each notional airbase is characterized by its location (the region number and forward or rear, or the COMMZ), by the number

[1]This type of analysis has previously been used for naval aircraft that are based on aircraft carriers and are used to provide CAS.

of aircraft of each type based on it, and by the number of SAMs and AAGs that are protecting it. These notional airbases can be pictured as moving as the FEBA moves. So if the FEBA were to move 200 km in the same direction in each sector, then each notional airbase can be thought of as moving 200 km in that direction; and the aircraft and SAMs and AAGs would move along with their airbase. Aircraft based on each notional airbase can be protected by shelters, but these shelters are not "part" of the airbase because the shelters are in fixed positions and do not move as the airbase moves. (It is possible also to play "movable" shelters in IDAGAM I, under some restrictive assumptions.)

c. Aircraft Shelters

IDAGAM I plays one type of shelter for aircraft on each side. These shelters provide protection for the aircraft from enemy airbase attacks.

With the exception just noted, these shelters are considered to be in fixed positions. Thus, for example, a shelter may initially be so far from the FEBA that it cannot be used even by aircraft based in the COMMZ. If the FEBA were to move closer and closer to that shelter, the shelter could be used first by aircraft based on the COMMZ airbase, then by aircraft based on the rear-region airbase, and finally by aircraft based on the forward-region airbase. Then, if the FEBA were to move still closer, the shelter would be considered to be too close to the FEBA to be used even by aircraft based on the forward-region airbase. Finally, if the FEBA crosses the location of the shelter (i.e., the shelter is overrun by the enemy), the shelter is assumed to be destroyed. The initial location of the shelters and the distances from the FEBA (that determine which shelters can be used by which notional airbases) are input. New shelters can be added (i.e., built) at any time during the war by input.

Aircraft are sheltered according to a priority-sheltering scheme, so that if type-3 Blue aircraft have a higher priority for sheltering than type-2 Blue aircraft, all type-3 Blue aircraft are sheltered on an airbase before any type-2 Blue aircraft are sheltered. The priority for sheltering is input.

d. Missions for Aircraft

IDAGAM I plays seven primary missions and five secondary missions for aircraft. The seven primary missions are

(1) Close air support (CAS)
(2) Close-air-support escort (CASE)
(3) Battlefield defense (BD)
(4) Airbase attack (ABA)
(5) Airbase-attack escort (ABAE)
(6) Airbase defense (ABD)
(7) Interdiction of divisions in reserve (IDR).

Aircraft on CAS missions attempt to fire on enemy divisions in combat. Aircraft on BD missions attempt to intercept the enemy CAS aircraft before they can fire at friendly divisions. Aircraft on CASE missions attempt to engage the enemy BD aircraft before those aircraft intercept the CAS aircraft. Aircraft on ABA missions attempt to destroy enemy aircraft on the ground (i.e., on enemy airbases). Aircraft on ABD missions attempt to intercept enemy ABA aircraft before the latter can destroy friendly aircraft on the ground. Aircraft on ABAE missions attempt to engage the enemy ABD aircraft before those aircraft can intercept the ABA aircraft.[1] And aircraft on IDR missions attempt to fire on divisions in reserve in regions.

[1]These interactions are not the only interactions possible. For example, since aircraft on ABA missions may have to pass over the battlefield in order to get to the enemy airbase, these aircraft might be engaged by enemy BD aircraft.

IDAGAM I requires as input the percent of aircraft of each type that are sent on each primary mission. (An input percentage could be zero for a mission if it is desired not to play that mission.) These input percentages can be changed over time by input, but IDAGAM I cannot internally calculate these percentages. Based on these input percentages and on other input parameters, IDAGAM I calculates which airbases the CAS missions come from and, based on where they come from, into which sectors they attack. Similarly, IDAGAM I calculates which airbases aircraft on the other missions come from and where they go to perform those missions (i.e., which enemy airbase ABA aircraft attack, which airbase ABD aircraft defend, etc.).

The five secondary missions are

(1) Supply-interdiction
(2) SAM-suppression against SAMs in combat sectors
(3) AAG-suppression against AAGs in combat sectors
(4) SAM-suppression against SAMs defending airbases
(5) AAG-suppression against AAGs defending airbases.

Aircraft on supply-interdiction missions attempt to block or destroy enemy supplies en route to the combat sector. (Supplies already in combat sectors can be destroyed by aircraft on CAS missions.) Aircraft on SAM-suppression missions attempt to destroy enemy SAMs in the appropriate locations, and aircraft on AAG-suppression missions attempt to destroy enemy AAGs in the appropriate locations.

A percentage of the aircraft on CAS missions are diverted from these missions and are assigned to fly SAM-suppression missions and AAG-suppression missions against the SAMs and AAGs defending in the sector in which those aircraft are attacking. What has just been specified for CAS missions holds

for aircraft on ABA missions and for SAMs and AAGs defending the airbases that those aircraft are attacking. These percentages are not fixed, but are based on input parameters, the number of sorties flown, the number of SAMs, and the number of AAG systems that are defending the appropriate target. An input percentage of the remaining aircraft on CAS missions and an input percentage of the aircraft on IDR missions are diverted from those missions and assigned to fly supply-interdiction missions. These five types of missions are called secondary missions because the number of aircraft assigned to them are determined as a percentage of aircraft assigned to primary missions.

Two types of aircraft missions that are not played in IDAGAM I are deep-supply-interdiction missions (for example, aircraft cannot be assigned to destroy supplies in the enemy's COMMZ or ports) and attack missions against replacements or divisions in reserve in the COMMZ.

e. Air Munitions

The number of types of air munitions that are considered in IDAGAM I is an input. For example, IDAGAM I could be played with nine types of Blue air munitions and five types of Red air munitions, where

Blue air munition type 1 = cannon;
Blue air munition type 2 = 2.75 FFAR (rockets);
Blue air munition type 3 = M-82 (iron bombs);
Blue air munition type 4 = napalm;
Blue air munition type 5 = cluster-bomb units of type 1;
Blue air munition type 6 = cluster-bomb units of type 2;
Blue air munition type 7 = rockeyes;
Blue air munition type 8 = cluster-bomb units of type 3;

Blue air munition type 9 = MK-84EO (smart bombs);

and

Red air munition type 1 = cannon;
Red air munition type 2 = iron bombs;
Red air munition type 3 = S-24 (rockets);
Red air munition type 4 = antipersonnel cluster-bomb units;
Red air munition type 5 = antiarmor cluster-bomb units.

Air munitions are used to determine the effectiveness of aircraft on CAS missions. This determination is made in a different way than for ground weapons. Each type of ground weapon has certain allocation and effectiveness parameters associated with it, and the types of ammunition for the ground weapons are not explicitly accounted for. However, the corresponding allocation and effectiveness parameters for air are associated with the various types of air munitions rather than with the types of aircraft. A notional load of the various types of munitions is input for each type of aircraft. (These notional loads can depend on whether the side is attacking or defending.) This notional load should be the weighted average of actual loads that aircraft of that type are likely to carry. The effectiveness of a CAS sortie of a particular type of aircraft is determined by the notional load of that type of aircraft and the effectiveness of each type of munition in that notional load. Just as ground ammunition is not played explicitly, neither are these air munitions played explicitly--in the sense that IDAGAM I does not keep track of a stockpile for each type of munition to determine when that type of munition is exhausted. (IDAGAM I accounts for consumption of supplies--which can include munitions--associated with aircraft, as described in Subsection 1.f, above.)

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3. Allocation of Resources

~~IDAGAM I is not an optimization model~~. Some of the resources played in IDAGAM I must be directly allocated by user-supplied inputs; others can be allocated either in this way or by the automated decision logic in IDAGAM I (along with user-supplied parameters for this logic). A few allocations must be made by the automated decision logic with user-supplied parameters.

Chapter II

DESCRIPTION OF IDAGAM I

A. OVERALL STRUCTURE

IDAGAM I is a fixed time-step model of a war between two sides. (It is possible to vary the size of the time-steps through sufficiently complicated inputs, but for all practical purposes IDAGAM I has fixed time-steps.) IDAGAM I does not model the events that might occur before the start of the war or the events that might occur after the end of the war, nor does it model how long the war will last. The number of time periods to be played must be input, and IDAGAM I will play this number of time periods regardless of what happens to either side. (Of course, the user could ask IDAGAM I to play, say, 90 time periods, then judge from the output that the war would have ended after the 45th time period, and then ignore all outputs after the 45th time period--a procedure that would give the same output as asking IDAGAM I to play 45 time periods.)

IDAGAM I places no formal restriction on how long these time periods should be. However, there are some logical difficulties in playing time periods shorter than one day (for example, there is no automatic way for IDAGAM I to distinguish a daytime period from a nighttime period). Accordingly, for the rest of this paper we will assume that the time period played in IDAGAM I is one day (24 hours). (If desired, IDAGAM I can be played with 2-day, 3-day, or longer time periods.)

In addition to the number of time periods (days) played, the user must input the conditions (forces and parameters) at

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the start of the first day and all new forces that are to be added to each side during the war. (The user can also change parameters during the war, if he so chooses.)

The basic operation of the model has the following nine steps:

(1) Read initial forces and parameters.

(2) Set up the theater controls for the first day of combat.

(3) Set the "day being played" counter equal to 1.

(4) Do the air-combat model for that day.

(5) Do the ground-combat model for that day.

(6) Test to see if the "day being played" counter equals the input number of days to be played. If so, stop; if not, continue.

(7) Do the theater-control model for that day.

(8) Read new parameters, read force increments, and read user-directed divisional moves as appropriate.

(9) Add 1 to the "day being played" counter and go back to Step 4.

Each of these steps is now discussed briefly and in turn.

Step 1. Except for the number of days to be played and a few "bookkeeping" inputs that are read into the model in the main control program (which is called MAIN in the IDAGAM I computer program), the initial inputs to IDAGAM I are read into the model in one of the following four subroutines:

Computer Program Name	Short Definition
(1) RCD	Read Campaign Description;
(2) RFTZ	Read Forces at Time Zero;
(3) RPTZ	Read (ground-combat and theater-control) Parameters at Time Zero;
(4) RPAC	Read Parameters for Air Combat (at time zero).

RCD reads the number of weapon types, division types, aircraft types, sectors, regions, etc., to be played in that run of the model. RFTZ reads the initial forces (both ground and air) into the model. RPTZ reads the parameters for the ground-combat model and the theater-control model. RPAC reads the parameters for the air-combat model. To read in these initial values, these subroutines are called only once.

Step 2. Before the first day of battle can take place, certain quantities must be calculated from the input parameters. This calculation is done in the Theater Control at Time Zero subroutine (which is called the TCTZ subroutine in the computer program). The quantities computed in TCTZ are of two types: First, there are some quantities (such as terrain and width of sector) that are determined in the theater-control model for the next day's battle; they are determined for the first day of battle in the TCTZ subroutine.[1] Second, there are some quantities (such as the value of a weapon against a standard force) that need to be computed only once for the whole war. Like the subroutines described in Step 1, the TCTZ subroutine is called only once per run of IDAGAM I.

Step 3. The model sets up the iterative procedure at this step. The "day being played" counter is initially set equal to 1 and, at the end of each iteration, 1 is added to this counter. The model will stop when this counter reads the input number of days to be played as described in Step 6.

Step 4. The air-combat model (called the AC program overlay in the computer program) calculates all air-to-air

[1]The theater-control model was not used here because it performs many other operations (besides determining these quantities) that do not need to be calculated before the first day of battle.

and ground-to-air attrition, the attrition of SAMs and AAGs due to suppression missions, the attrition of aircraft on the ground due to ABA missions, and the attrition to divisions in reserve due to IDR missions. The number of surviving aircraft by type on CAS missions calculated by this model are used as input to the ground-combat model. On each day of the war, the air-combat model is called.

Step 5. The ground-combat model (called the GC program overlay in the computer program) calculates the rest of the air-to-ground losses and all ground-to-ground losses (i.e., it calculates the attrition of people, weapons, and supplies in combat sectors due to enemy ground fire and enemy CAS missions). The ground-combat model also calculates the capture of territory, which is denoted by the movement of the FEBA in each sector. Like the air-combat model, this model is called on each day of the war.

Step 6. At this point in the program, the model compares the "day being played" counter and the input, which gives the number of days to be played in that particular run. If the counter and this input are equal, then the model stops. If they are not equal (i.e., if the number of days already played is less than the input number of days to be played), then the model continues. In a normal run, this is the only step at which the model can terminate.

Step 7. The theater-control model is divided (for computer purposes only) into two program overlays (called TC1 and TC2). The main functions of the theater-control model are to add replacement people and replacement weapons to divisions, to move reinforcement weapons to divisions, to move reinforcement divisions from the COMMZ to regions and from regions to sectors,

and to withdraw divisions from sectors to regions, as appropriate, for each side. In addition to playing the reinforcement and reserve policies for each side, the theater-control model makes a number of other computations (such as moving supplies and determining geographical quantities). Since the theater-control model is not used before the first day of combat, and since it is not needed on the last day of combat, it is called one less time than the total number of days played.

Step 8. If the user so desires, on any day of the war he can read new values for parameters and new force increments into the model; and he can direct divisions to be moved in the model. New parameters (both ground and air) are read in the RP subroutine. If a new value for a parameter is read into the model, it replaces the old parameter. Force increments (both ground and air) are read in the RF program overlay. If a force increment is read into the model, it does not replace (but, rather, adds to) the force already there. For example, if 10 aircraft of a particular type are added to a certain airbase that already has 20 aircraft of that type stationed on it, the model will start the next day with 30 aircraft of that type on that airbase. The theater-control model automatically moves divisions between regions and sectors according to certain rules. However, whenever the user would like to direct particular divisional moves, he can do so by reading in a negative value for the number of divisions, the appropriate negative number of people and weapons by type for the old location, and the corresponding positive numbers for the new location. But he can also move forces by using the MF subroutine. This subroutine requires only the number and type of divisions to be moved and the location from which and to which they are to be moved. The MF subroutine then automatically computes the number of people and weapons by type to be moved.

Step 9. At this step, the model increments the "day being played"counter by 1 and starts the next day of combat by sending control of the program back to Step 4.

(Steps 4, 5, and 7--the air-combat, ground-combat, and theater-control models--are outlined below.).

B. STRUCTURE OF THE AIR-COMBAT MODEL

The air-combat model performs the following steps:

Step 1. The first operation performed by the air-combat model is to determine the number of shelters associated with each notional airbase. This determination is made by comparing the location of the FEBA (which is input for the first day and moved according to the ground-combat model on each day of the war) to the fixed locations of the remaining shelters (which are input).

Step 2. The second step is to compute the number of supplies consumed by the aircraft and associated men and equipment. If enough supplies are not available, the number of sorties that can be flown that day is reduced according to the shortage of supplies.

total tonnage

Step 3. The third step is to compute the assignments of aircraft by location. IDAGAM I requires as input the percent of aircraft of each type that are to be assigned to each primary mission. Based on these input percentages, the situation of ground forces, the number of aircraft of each type on each airbase, and other parameters, the model computes which airbases the aircraft on CAS missions come from and which sectors they attack; and it computes which airbases the aircraft on ABA missions come from, which enemy airbases they attack, and so on, for the other five primary missions.

Step 4. This step multiplies the percent of assignments generated in Step 3 by the number of aircraft by type on each airbase, to obtain the actual number of aircraft on each mission by type and by location where these aircraft are attacking.

Step 5. In this step, a percentage of the aircraft on CAS missions in each sector are diverted from those missions to suppress the enemy SAMs and AAGs that are defending in that sector. The percentage of aircraft that perform these suppression missions depends on the number of aircraft on CAS missions in that sector, the number of SAMs in that sector, and the number of AAGs in that sector. Also, a percentage of aircraft on ABA missions against each airbase are diverted from those missions to suppress the SAMs and AAGs that are defending that airbase. This percentage also depends on the numbers of (1) aircraft on ABA missions against that sector, (2) SAMs defending that airbase, and (3) AAGs defending that airbase.

Step 6. In this step, all air-to-air attrition is computed. The results of this step are the number (by type and by mission) of aircraft killed and the number surviving on each airbase. The number of surviving aircraft on CAS missions are input to the ground-combat model. The number of surviving aircraft on ABA missions are used in Step 7 to compute aircraft losses on the ground. The attrition of SAMs and AAGs by aircraft on suppression missions is also computed in this step.

Step 7. The attrition of aircraft on the ground by enemy aircraft on ABA missions is computed in this step.

Step 8. The attrition to divisions in regions due to IDR missions is calculated in this step.

C. STRUCTURE OF THE GROUND-COMBAT MODEL

The ground-combat model performs the following steps:

Step 1. The attrition and FEBA-movement calculations need to be made each day for each combat sector. The first step in the ground-combat model is to set the sector index equal to 1. This index will be incremented each time through the attrition and FEBA-movement calculations until all sectors have been considered.

Step 2. This step examines each of the opposing forces in the sector under consideration and degrades a force if it is not at least roughly balanced. (A force is not "balanced" if it has too many of certain types of weapons--e.g., artillery--and not enough of other types of weapons.)

Step 3. In this step, the ground model determines who will be on attack in the sector. (A side might be on defense in general, but might attack in a particular sector if it is strong enough in that sector.) If neither side is strong enough to attack, then a holding posture is said to exist in the sector.

Step 4. The ground model computes separately by weapon type a potential number of weapons lost (due to enemy air and ground fire) and the number of casualties per weapon lost, and the total number of casualties. Based on these three quantities, the model computes by weapon type the (actual) number of weapons lost.

Step 5. In this step, the weapon losses are prorated by type to the divisions in the sectors; and the total number of casualties are divided into combat, combat-support, and service-support categories and applied to the divisions in the sector.

Step 6. The movement of the FEBA in the sector under consideration is calculated in this step.

Step 7. The amount of supplies in a sector can be reduced by consumption and by losses to enemy (air and ground) fire. This step computes the amount of supplies consumed and the amount of supplies lost to enemy fire.

Step 8. A certain percentage of the weapons lost is assumed to be only damaged and capable of repair. This percentage can depend on the side losing the weapons, on whether that side is on attack or defense in the sector, on posture, and on weapon type. This percentage is applied by weapon type to the number of weapons lost, to determine the number of weapons to be added to a weapons "recovered and repairable" pool. When these weapons have been repaired, they will be added to the weapon replacement pool in the COMMZ.

Step 9. Nonbattle casualties are computed in this step for people in the sector.

Step 10. The sector index is compared to the total number of sectors in this step. If the sector index is less than the number of sectors, then the sector index is incremented by 1; and control of the model is sent back to Step 2. If all sectors have been considered, the model continues to Step 11.

Step 11. The final step of the ground model is to adjust the FEBA for front-to-flank considerations. The way that this adjustment is made is by first considering the attacker's front-to-flank ratios. If the attacker cannot sustain these ratios (as determined by various input-parameters and decision rules), then the FEBA is moved back in appropriate sectors until a

sustainable position is reached. Then the defender's front-to-flank ratios are considered, and the defender is forced to withdraw in those sectors where his front-to-flank ratios are not sustainable.

D. STRUCTURE OF THE THEATER-CONTROL MODEL

The theater-control model consists of the following steps:

(1) Compute supply consumption in regions and COMMZ.

(2) Compute nonbattle casualties in regions and COMMZ.

(3) Add daily replacement people, weapons, and supplies to the replacement pools in the COMMZ.

(4) Compute personnel and weapon replacements for divisions in sectors and regions.

(5) Consider delayed effectiveness of personnel replacements.

(6) Compute theater attacker and sectors of main attack.

(7) Compute geographical quantities.

(8) Compute and move reinforcing divisions from COMMZ to regions.

(9) Compute and move reinforcing divisions from regions to sectors and withdrawing divisions from sectors to regions.

(10) Compute shipment of supplies and supply losses due to enemy aircraft on supply-interdiction missions.

Each of these steps is now discussed briefly and in turn.

Step 1. Supply consumption for divisions in sectors was computed in the ground-combat model. This step computes supply consumption for divisions in regions and the COMMZ, for people and weapons in replacement pools in the COMMZ, and for theater-support personnel in the COMMZ.

Step 2. Nonbattle casualties are computed here for people in regions and the COMMZ.

Step 3. Additional people, weapons, and supplies can be read into the appropriate replacement pools using the RF (Read Forces) subroutine. But to simulate daily arrivals of these quantities into the theater using the RF subroutine would require calling this subroutine each day of the war. Since replacement people, weapons, and supplies are likely to arrive on a regular basis, IDAGAM I allows each of these pools to be incremented on a daily basis, and the size of the increment can vary linearly over time. These daily increments are made in this step.

Step 4. Replacement personnel and weapons are added into under-strength divisions in regions and sectors in this step. (Replacements are not automatically added to divisions in the COMMZ.)

Step 5. Delayed effectiveness of personnel replacements is considered as follows: Suppose that according to Step 4 a division is to receive r replacements on day d. Suppose that a replacement is assumed to have a fractional effectiveness of x_1 on his first day with the division, a fractional effectiveness of $x_1 + x_2$ on his second day with the division, and so on--until he reaches full effectiveness on his n^{th} day with the division. (The values of n and $x_1, \ldots, x_{n-1}$ are input; and $x_1, \ldots, x_{n-1}$ must satisfy the conditions that $x_i \leq 0$ for all $i \leq n - 1$ and $1 \geq x_1 + \ldots + x_{n-1}$.) IDAGAM I plays this by adding $x_1 r$ replacements to the division on day d, $x_2 r$ replacements on day d + 1, and so on--until it adds $(1 - x_1 - \ldots - x_{n-1})r$ replacements to the division on day d + n - 1.

Step 6. The side that is the theater attacker is determined by input on the first day of the war. For each succeeding day, the model determines the total attack value summed over all divisions and all aircraft in the theater for each side. The side with the higher total attack value is assumed to be the

the theater attacker that day. The sectors of main attack for the side that is the theater attacker are then computed. These sectors of main attack can either be determined by input or be computed by the model. If they are to be computed by the model, the model will compute one sector of main attack in each region and, at the user's option, this can be either the sector with maximum penetration or the sector with minimum penetration.[1]

Step 7. Geographically related quantities (such as terrain, posture, and width of sector) are determined for each sector in this step by comparing the current location of the FEBA in the sector to inputs which give these geographical quantities as a function of FEBA position.

Step 8. Reinforcing divisions are moved from the COMMZ to region in this step, as follows: A number of parallel phase lines that run the width of the theater and that can be of variable distance from each other are inputs to the model for each side. Associated with each space between these phase lines is an input fraction between 0.0 and 1.0. The sector in the theater with maximum penetration is determined, and the phase lines (between which the FEBA location in this sector falls) are found.[2] The input fraction associated with the space between

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[1]The idea here is that if the side that was initially the theater defender became, through reinforcements, the theater attacker, then that side might want to push the enemy out of his territory. This strategy is accomplished by selecting the sector of main attack to be the one with the minimum penetration. Once the enemy is pushed back of the original FEBA position in all sectors, the model will automatically begin to compute the sector of main attack as the one with the maximum penetration.

[2]If the user has opted to have the model select the sector of main attack according to the sector with minimum penetration, then (for the attacker only) the sector with minimum penetration is used (instead of the sector with maximum penetration).

these phase lines determines the fraction of the side's total ground force that the side wants to keep in reserve in the COMMZ (there are different phase lines and different fractions for each side). If the side has more than that fraction of his force in the COMMZ, the remainder is sent forward to the region that contains the sector of maximum (or, if appropriate, minimum) penetration.

If the user of IDAGAM I desires to direct the movement of divisions by input rather than by the logic described above, he can do so. To do so here, the user can input the number 1.0 for the fractions associated with all spaces between phase lines, which would mean that no divisions could be automatically moved from the COMMZ to regions. The user could then direct the movement of divisions by input using the MF (Move Forces) subroutine.

Step 9. Reinforcing divisions are moved from regions to sectors, and withdrawing divisions are moved from sectors to regions in this step. (Since divisions are in reserve whether they are in regions or in the COMMZ, the model does not automatically withdraw divisions from regions to the COMMZ.)

Step 10. Supplies can be located in each sector, in two places in each region, and in two places in the COMMZ. The amount of supplies shipped to each location and supply losses due to enemy aircraft on supply-interdiction missions are computed in this step.

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Summary Comments on the
IDA TACTICAL NUCLEAR WARFARE (TACNUC) MODEL

by

E. Kerlin

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ABSTRACT

The IDA Tactical Nuclear Warfare (TACNUC) Model was developed for the purpose of assessing the interaction of conventional forces and nuclear weapons in a combined conventional/nuclear war at the theater level. TACNUC currently contains the following five component models:

- An *Air-Combat Model* that determines the allocation of aircraft to specific combat missions, on the basis of either general or specific user-input allocations, computes (from various ground and air sources) attrition to tactical aircraft, and provides close air support missions for use in the ground model.
- A *Ground-Combat Model* that determines attrition to people and weapons, by type, within division-size combat units as they interact in battle areas across the theater. Movement of the forces occurs from area to area within a battle sector as a result of one side's dominant ratio of air and ground weapons in the sector.
- A *Target-Acquisition Model* that determines the expected number of targets acquired by type and location over the length of a target-acquisition cycle--given various input data on sensors, targets, and the environment. The model assumes that the general locations of major combat forces are known and that both sides operate sensors to acquire candidate targets for possible nuclear fires.
- A *Nuclear Model* that accounts for the assignment and assessment of nuclear weapons against various types of targets throughout the theater. The assignment of weapons to targets are either user-specified or developed from user input by an internal assignment procedure. Nuclear-damage assessments are made in an expected value sense using analytic functions to provide a rapid analysis of nuclear-weapon use. Firing constraints due to population centers are observed, and civilian casualties are assessed where necessary.
- A *Supplies Model* that determines the flow of supplies within the theater, on the basis of two levels of resupply. A major resupply cycle uses an efficient transshipment algorithm to decide how supplies flow in a structured node-arc network from surplus nodes to deficit nodes. In a minor resupply cycle, supplies flow from supply nodes to demanding units to satisfy daily demands. When supplies are low, effectiveness of combat units is degraded and air sorties are reduced.

Model Control provides the overall model structure, within which the component models operate. This routine acts as a buffer, transmitting information when and where required among the models. The routine allocates arriving resources to various areas, moves units into combat or into reserve (on the basis of input parameters and model logic), and in general does detailed bookkeeping on the many resources that are required by the component models.

Chapter I

INTRODUCTION

A. OBJECTIVE

The objective of this study is to develop a model that can be used to assess tactical nuclear warfare between NATO and Warsaw Pact forces in Central Europe.

B. SCOPE

The model is intended to be used to evaluate the interaction of conventional forces in a theater-level conventional war as well as the interaction of conventional forces and nuclear weapons in combined conventional-nuclear war with varying degrees of nuclear employment. The complete range of tactical weapon systems, both nuclear and nonnuclear are considered in their attacks on military targets throughout the theater area of interest. Military targets consist of combat maneuver units, nuclear and nonnuclear weapon systems, air defense units, airbases and supply depots.

It is intended also that the model be used to evaluate various doctrines or policies of employment of nuclear weapons. Since NATO and Warsaw Pact concepts of nuclear weapon employment may differ significantly on what specific results should or could be attained with conventional and nuclear weapons, the nuclear employment doctrine should be flexible enough to capture existing asymmetries of philosophy or policy of employment. The aims of developing a flexible employment structure or of selecting a plausible range of employment options for each side are to insure that the doctrines of nuclear response can be realistically evaluated, and to confront the opposition with a sufficiently complete spectrum of alternatives that may serve to deter continued attacks.

Finally, it is intended that the model assess collateral damage to civilian population resulting from the attack of tactical targets with nuclear weapons. Not only assess the damage from nuclear weapons fired, but to consider initially the existence of population centers as constraints to firing the weapons.

The study was confined to the area of Central Europe because that contingency dominates the requirement for US conventional and nuclear general purpose forces. The resulting modeling methodology, however, is not limited to that area and can be adapted for use in other areas by appropriate data changes.

C. BACKGROUND

Anticipated reductions in the strength of US general purpose forces and the ongoing talks with the Soviets on Mutual and Balanced Force Reductions (MBFR) in Vienna have led to renewed interest in tactical and theater nuclear forces and in the possibility that nuclear capabilities may compensate for the reduction in conventional forces. An examination of this possibility requires an integrated analysis of all force components. The US military, in general, and the JCS/SAGA, in particular, have shown increasing concern over the tendency to evaluate conventional and nuclear components separately. A separate analysis of each component neglects the interactions among the components, particularly the impact of withheld nuclear capabilities on the conventional war and the contribution of conventional forces in a nuclear war.

In addition, the ever expanding interest in developing new concepts of fighting a limited nuclear war, to include flexible employment options, well-defined steps in escalation control, and means for reducing collateral damage, all tend to reinforce the desirability of planning conventional forces and nuclear weapons in an integrated way. After all, the more limited the use of nuclear weapons, the more important the contribution of conventional forces to the desired outcome.

However, it is very clear that only in a dynamic context can the numerous conventional and nuclear force components interact in a meaningful way to shed some insight on these difficult problem areas. With this understanding and concern about the problems faced by force planners, the Director, Joint-Staff, requested that the Weapons Systems Evaluation Group develop a theater level model that could be used for assessing the interactions between conventional forces and nuclear weapons.

This report describes the theater level nuclear warfare model (TACNUC) developed by the Institute for Defense Analyses, in support of the Director, Weapons Systems Evaluation Group, in response to that request.

Chapter II

ELEMENTS OF THE MODEL

A. THREATER STRUCTURE

The TACNUC model is designed to be a theater-level nuclear warfare model that can be used to assess the interaction of conventional forces and nuclear weapons in a combined conventional-nuclear war. The conventional and nuclear weapons are delivered by ground and air delivery means anywhere in the theater.

The elements of the theater structure as designed for these assessments include sectors, battle areas, regions, and the COMMZ, as described below.

1. Sectors

The theater structure is built around a series of nonintersecting geographical sectors that cover the theater area of interest. These sectors are considered as avenues of advance that run the length of the theater and are of variable width. Each sector is divided into a stated number of intervals that are used to portray terrain type variations, width of sector variations, and barrier variations. Intervals are of constant width but variable depth, with terrain or barrier assumed to be constant throughout the interval. Barriers represent the existence of man-made barriers such as defensive positions, or large cities or natural barriers such as rivers or mountains. All items of interest to the model will be located either at some fixed distance from the Red base point in each sector or given a general location with respect to some battle area.

2. Battle Areas

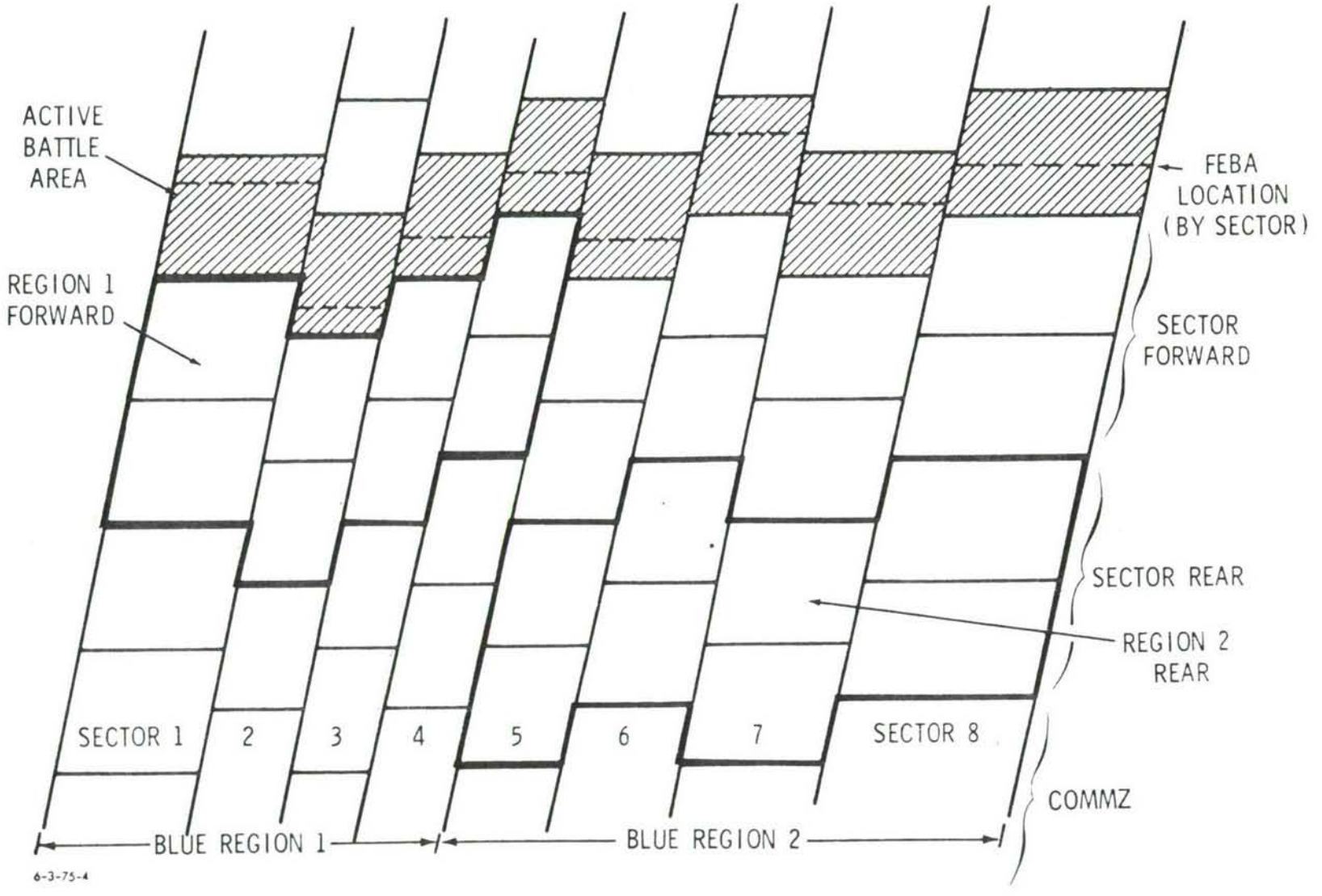
Battle areas are the geographical subdivisions of the battlefield, on a sector-by-sector basis, that provide for easy location of elements played in the model. The width of a battle area is the same as the sector width but of any depth as defined by the user. An important feature of the battle area structure is shown in Figure 1. From any battle area, within a particular internal sector, there are six well-defined directions of movement. For the initial use in the TACNUC model, movement resulting from combat actions will be forward or backward in each sector. However, forces may be moved in any of the other four directions to reinforce adjacent sectors where combat is occurring provided the move does not result in forces being moved into an active battle area. (Note: In order to play moves of combat forces in all six directions, and especially moves into active battle areas, requires very detailed logic on when, where, and how much force to move. The complexity of decision rules to make these moves is felt to be beyond the scope of this model's ground combat logic. Thus, in this initial version of the TACNUC Ground-Combat Model, moves of combat forces are limited to those specified above.)[1]

Battle areas within which ground combat occurs are termed *active battle areas*, while all others are termed *inactive battle areas*. Units directly involved in the ground combat are assumed to be located in the active battle area, while units not involved in combat are located in one of the other inactive battle areas within the theater. Daily combat activity creates an ebb and flow of the forward edge of the active battle area, or more commonly called FEBA. As the FEBA moves toward the Blue side the FEBA location will be ever increasing.

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[1]The logic for handling an entire spectrum of tactical moves, on a hexagon-based area of war, is the central theme for the maneuver-oriented ground combat model, IDAHEX, now being developed by Paul Olsen at IDA.

TACNUC THEATER STRUCTURE (BLUE SIDE)



3. Regions

Regions consist of the rear portion of one or more geographical sectors, beginning at the rear of the active battle area and extending to a predefined depth. The regions are a convenience for controlling the assignment of combat units to battle areas, and tactical aircraft to air missions. One or more geographical sectors are grouped into a region, but this grouping need not be the same for both sides. The only restriction is that each region boundary must coincide with some sector boundary and hence a boundary of some battle area. Each region is divided into two parts: a forward region and a rear region. These two parts are created to provide the Air-Combat Model with the capability of representing, in a stylized way, varying range capabilities of different aircraft.

4. COMMZ

The COMMZ is an area to the rear of the rear region that spans all sectors in the theater. The COMMZ is used for receiving the arriving combat units, tactical aircraft, supplies, and replacement weapons and personnel. The COMMZ serves as a holding area for combat resources and provides airbase facilities for long range tactical aircraft.

Even though the enemy advances sufficiently far to cause the COMMZ area to collapse into the rear region, the COMMZ function of receiving units, supplies, and replacements continues to exist. However, the specific airbase facilities that once composed the notional COMMZ airbase now compose the rear region airbases. The new COMMZ airbase is assumed to be located in sanctuary areas and serves as an "out-of-theater" COMMZ airbase.

In summary, the theater structure of the TACNUC model provides for sectors, battle areas, regions, and a COMMZ. Any element played in the model can be located by its association with a specific battle area, either active or inactive. All other elements of the theater structure are used as controlling mechanisms

to assign various resources to particular areas of the theater: sectors are used as the mechanism for assigning units to combat and for subsequent movement of forces; regions are used as the mechanism for assigning tactical aircraft to missions throughout the theater, and for assigning combat forces to sectors; the COMMZ provides for the central control and storage of all resources entering the theater.

B. MODEL OPERATION: AN OVERVIEW

The TACNUC model is made up of submodels and a control framework that allows friendly and enemy forces, employing both nuclear and conventional weapons, to interact on a theater-wide scale. There are five basic submodels in this structure: a Ground-Combat Model, an Air-Combat Model, a Target Acquisition Model, a Nuclear Model, and a Supplies Model. These models are linked together and controlled by a model control process which acts as a buffer, transmitting information among the models when and where required. The components of the TACNUC model are linked together in an operational sense as shown in Figure 2.

The model control routine using both scenario information and user supplied input directs the overall operation of the TACNUC model. When the user does not provide direct assignments of weapons and forces, the model operation is guided and controlled by internal decision rules via the model control routine. This routine allocates arriving resources to various areas within the theater, moves units into combat or into reserve based on input parameters and model logic, and in general, does detailed bookkeeping on the many resources that are required by the other models.

A brief functional description of the component models is presented below.

1. Air-Combat Model

The Air-Combat Model is designed to assess the effects of opposing tactical air forces interacting with an opponent's air

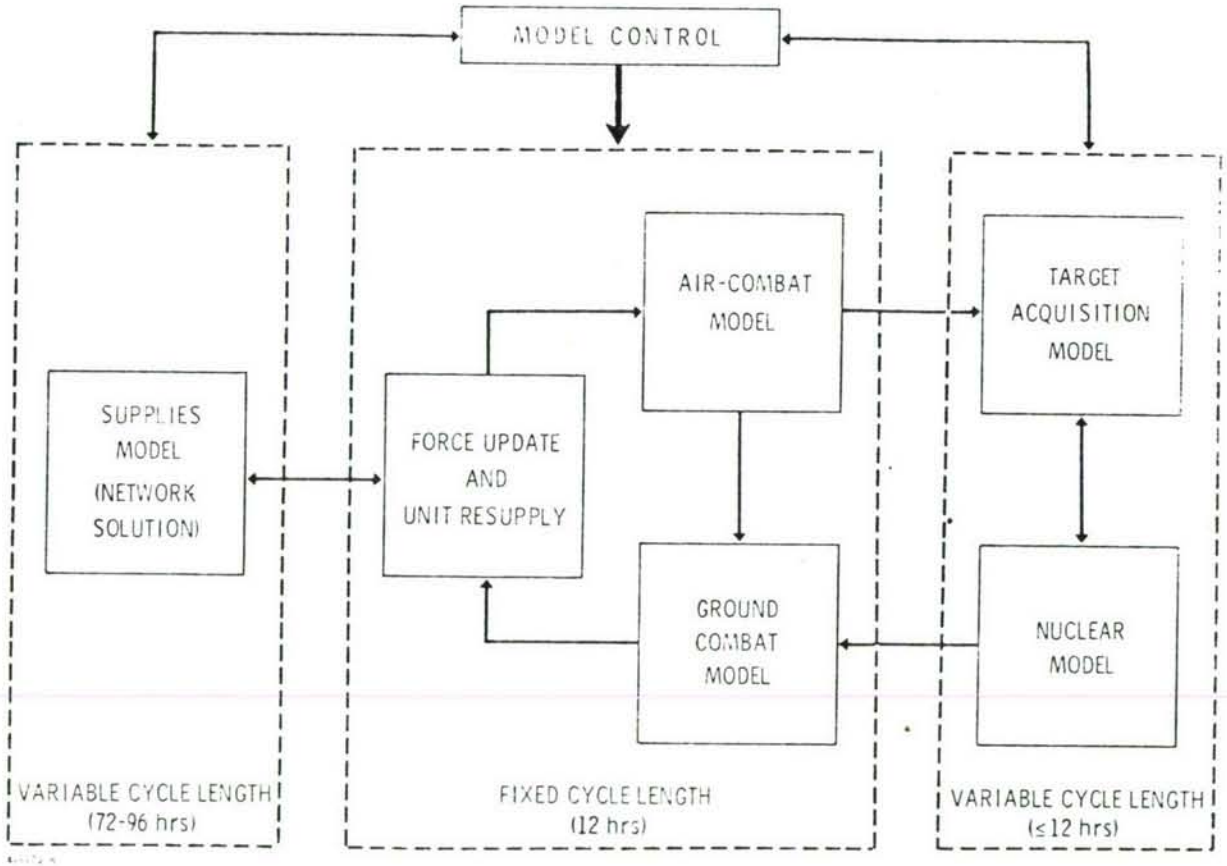


Figure 2. OPERATIONAL STRUCTURE OF THE TACNUC MODEL

and ground resources. For each 12 hour combat cycle, model control transmits to the air model the level of air defense weapons in the theater and the status of air resources for both sides (less any nuclear-capable aircraft that are withheld for use by the Nuclear Model).

The assignment logic of the air combat model assigns the inventory of aircraft for a given cycle to various missions throughout the theater. The assignment is given in terms of the fraction of aircraft, by type, to be used on each of six combat missions. The six missions are: airbase attack, close air support, interdiction, escort, battlefield defense, and area defense. The escort missions, in addition to providing aerial escort for attack aircraft, conducts SAM suppression on point and area deployed SAMs. A seventh mission, tactical reconnaissance, is played also.

The assignment logic is designed for use in one of three ways.

(a) Completely dynamic in nature such that the assignment in a given period depends upon the assignment in previous periods as well as upon other selected factors; e.g., period-by-period aircraft loss rates.

(b) Completely user input controlled such that all assignments are specified for the entire length of the campaign. Changes in the assignments may be made for certain periods but these must be input initially with all other assignments.

(c) Some combination of (a) and (b) such that the user may specify only the attack aircraft assignment while the assignment of defense aircraft is handled by the model logic.

The three way use of the assignment logic works as follows: whatever amount of input the user decides to provide on aircraft assignments to missions acts as an override to a mission-assignment matrix that is contained within the program. If the user provides the required threshold values to initiate the assignment matrix, then (a) above is implemented. If the user decides to make all of the aircraft-mission assignments for all periods of a campaign, the matrix is never called and (b) above is implemented. If the user specifies assignments for the attack aircraft only then (c)

above is implemented, and the defense aircraft are assigned by internal decision rules.

Aircraft allocated to airbase attack are assigned in an optimal fashion to specific airbases based on airbase location (forward or rear region), range of aircraft, and the effectiveness of aircraft to kill sheltered aircraft and unsheltered aircraft, with the objective of maximizing the number of enemy aircraft killed. The marginal allocation solution procedure to this optimization problem is discussed in Volume II, Appendix A.

Aircraft allocated to close air support are further assigned to sectors (i.e., active battle areas) by the decision rules in the air model. The number of aircraft, by type, with their specific munitions loading and user input allocation of fire to type targets, add a certain amount of firepower to the ground battle with which to inflict casualties and destroy weapons and supplies in combat divisions.

Aircraft assigned to interdiction missions are directed to attack long-range missile sites in region areas, to combat divisions in forward inactive battle areas, and to supply depots in the forward and rear regions.

Aircraft can encounter air defense weapons on all attack missions. In the active battle areas there are short range SAMs and AAA with divisions for defense of the battlefield. To the rear of combat units that are near the FEBA is the area SAM belt to defend against deep attacks. And at each primary target such as airbase, supply depot, or long range SAM site, there may be short range air defense weapons such as SAMs or AAA, called point defenses.

To increase chances of surviving the expected high density of air defenses on either side of the FEBA, the air logic allows each side to use saturation tactics. That is, offensive aircraft penetrate in large numbers, in a well-coordinated attack, in a selected number of attack corridors. Once through the corridor,

the attack aircraft and escorts, fan out and attack primary targets such as airfields, supply depots and long-range SAM sites. Air defense fighters engage these attack aircraft and escorts once through the corridor but prior to their arrival in the primary target area.

Aircraft assigned to air defense are further allocated to battlefield defense and to rear area defense (i.e., defense of airbases and supply depots) in proportion to the number of enemy aircraft attacking thest targets. Aircraft on battlefield defense patrol the front in each sector and attempt to engage opposing aircraft on close air support missions. However, there are times when the enemy uses penetration corridors in a few of the sectors. In these sectors, the battlefield defense aircraft encounter all types of incoming attack aircraft at random. Engaged attack aircraft are assumed to drop their munitions and engage in air-to-air combat. Those not engaged continue on to their target. Aircraft assigned to area defense against deep attack missions are assumed to be alerted by forward intercept means and develop an air defense screen against the penetrating attackers. As with battlefield defense, some of the penetrators are detected, drop their munitions and engage in air-to-air combat. Those not engaged continue on to their target.

The sequence of interactions for the deep attack aircraft is (1) encounters with battlefield defense aircraft (in sectors of corridor penetration), (2) encounters with area-deployed SAMs (with or without defense suppression), (3) encounters with area defense aircraft, (4) encounters with point air defense weapons (SAMs and AAA) at the target area, and (5) attack of primary targets. The sequence of events for close air support aircraft and their escorts is (1) encounters with battlefield defense aircraft, (2) encounters with short range SAMs and AAA located in combat units (with or without defense suppression), and (3) attack of combat divisions in the assigned active battle areas.

Elements of the Air-Combat Model are summarized in Figure 3.

When the Air-Combat has completed a combat cycle, it sends back to model control the status of air resources updated with the results of this 12 hour cycle operation. In addition, the number of attack aircraft successfully penetrating air defenses to attack close air support targets and supply targets are transmitted to the Ground-Combat Model and the Supplies Model, respectively. Available reconnaissance aircraft are made available to the Target Acquisition Model.

When combat conditions or worsening tactical situations signal the probable use of nuclear weapons, model control transmits to the Target Acquisition Model the status and resource levels of opposing ground units, and the number of reconnaissance aircraft. The Target Acquisition Model then utilizes these aircraft and sensors, along with ground sensors to acquire candidate targets for possible nuclear attacks as described in the next section.

2. Target Acquisition Model

In a combat situation where tactical nuclear weapons might be used, the process of target acquisition is particularly important since nuclear weapons are a very expensive, very lethal resource, that should be applied only to the most militarily significant targets. Thus, in a model of tactical nuclear combat it is desirable that target acquisition be played in a realistic way so that the capability of the opposing forces to acquire targets can be represented in an objective manner.

The Target Acquisition Model deals with probabilities of target detection because: (i) it is not certain that detection is possible under all environmental and physical conditions, and, (ii) even when detection of a target is possible, it is not certain to occur due to a number of interfering factors. In the model the probability of target detection is made a function of a number of environmental and physical variables.

- Considers six combat missions:
  - Close air support (CAS)
  - Airbase attack (ABA)
  - Interdiction (INT)
  - Escort (ESC)
  - Battlefield defense (BD)
  - Area defense (AD)
- Considers seven types of combat aircraft plus one notional-type reconnaissance aircraft.
- Determines number of aircraft, shelter, and air defense elements associated with each notional airbase.
- Computes assignment of attack aircraft to target areas
  - CAS aircraft to active battle-areas
  - ABA aircraft to notional airbases
  - INT aircraft to missile sites, reserve divisions, and supply depots
- Computes assignment of fighter aircraft to defense mission on day n, on the basis of number and type of friendly attack missions and total enemy air missions on day n.
- Considers aircraft-attrition rates by type of mission, as a basis for modifying assignments on any day.
- Computes attrition to aircraft from air-to-air combat, air-base attacks, and from SAMs and AAA on the ground.

Figure 3. AIR-COMBAT MODEL

It is assumed that the general location of the major NATO and Warsaw Pact forces is known across the theater. Both sides operate sensors to acquire candidate targets for possible nuclear fires. The targets are positioned within range zones of stylized division arrays. Some of the sensors are located within a sensing division itself and move with the division (e.g., ground sensors), while others are associated with aircraft stationed at fixed geographical positions (e.g., air-carried sensors) and are allocated to different target divisions by sensor allocation rules.

a. The Targets and Sensors

Given various input data on sensors, division-sized targets, and the environment, the Target Acquisition Model computes the expected number of targets, by type and location, within a division-sized unit that are acquired during a 4-hour target acquisition cycle. These detections are then sent to the Nuclear Model as targets for possible nuclear attacks.

The primary targets for nuclear weapons are maneuver units and counterforce weapons. The specific targets considered in a Soviet division array are motorized rifle companies, tank companies, SSM batteries, SAM batteries, conventional and nuclear artillery batteries, and various headquarters.

It is assumed that the targets are located within a rectangular area called a unit array which is further subdivided into smaller rectangles called zones. The zones are distinguished by their distance from the front of the array. Within a zone the targets are assumed to be uniformly distributed on a line across the width of the zone.

In addition, there are such a large number of different types of sensors that can be used to acquire targets that a dominant set of sensors was chosen to simplify the analysis. A convenient way to classify the various sensors is according to their mode of operation. Such a list might include the following--

STANDOFF (FIXED)

- Visual: unaided or aided.
- Radar: counterbattery, countermortar, and surveillance.

STANDOFF (MOVING)

- Helicopter or Mohawk with photo, infrared, and SLAR.

PENETRATING

- RF-4C or Drone with photo, infrared, and SLAR.

Since ground sensors are located within combat divisions their employment depends on how many friendly and enemy divisions there are in the area. Thus, ground sensors are allocated to target divisions as follows. Let

N_B = the number of Blue divisions on-line in the sector.

N_R = the number of Red divisions on-line in the sector.

Then each Red target division is assumed to interact with N_B/N_R Blue sensing divisions and sensors. Similarly, each Blue target division is assumed to interact with N_R/N_B Red sensing divisions and sensors.

The procedure for allocating army air sensors is to take the total friendly army air assets associated with units in a sector and apportion them equally against opposing enemy units on-line in the sector. These sensors are assumed to fly in a standoff mode over the target divisions.

Air Force aircraft and sensors are allocated to various sectors based on decision rules in the Air Combat Model such as to sectors in proportion to the number of enemy forces located there. These aircraft are assumed to fly in a standoff or penetrating mode over the sector to which they are assigned. Air Force aircraft also fly deep search missions attempting to detect targets that are located in areas not adjacent to the FEBA.

b. The Target Acquisition Equations

The goal of the target acquisition model is to compute the probability that a target located in a particular unit array is acquired by all the sensors that are operating to acquire targets in that array. Referring to this target generically as target j, it is assumed that the probability that target j is acquired by all sensors in time I is given by

$$P_A(j) = 1 - \prod_{m=1}^{M} \prod_{i=1}^{N_m} \left\{1 - P_A(i,j,T)\right\}$$

where

$P_A(i,j,T)$ = probability that target j is acquired by sensor i, in time T.

M = the number of types of sensors.

N_m = the number of sensors of type m.

The above expression is valid provided that all sensors operate independently. Once $P_A(j)$ is computed the expected number of targets acquired of the same type as target j is given by the sum of the probabilities that each is acquired. This quantity is then input to the Nuclear Model as one entry in a list of possible targets.

The quantity $P_A(i,j,T)$ which produces $P_A(j)$ is based on sensor and target characteristics, weather, and terrain.

Weather influences target acquisition in two ways. If a sensor requires that a target be optically visible in order to be seen by the sensor, then the range from sensor to target may not exceed the visibility range for acquisition to occur. If a sensor is air-carried and requires a minimum flight ceiling to operate, then it is used only if the ceiling exceeds the minimum required calue. Both of these weather factors are played by inputting a typical sequence of ceiling and visibility values to the model.

The effect of terrain is accounted for through a line-of-sight equation. Acquisition can occur only if a line-of-sight exists between the sensor and the target and the probability of its existence depends upon the vegetation and topography of the target location and the altitude of the sensor.

Given the above environmental relations, the value of $P_A(i,j,T)$ is based on choosing from one of two models of searching for a target: a model which supposes that the sensor continuously searches for a target or a model which views the sensor operating in discrete glimpses. In both models the basic ability of the sensor to detect the target must be input as a parameter. This, along with the mode of sensor operation and some operational parameters (altitude and velocity of the sensor) produce a numerical value for $P_A(i,j,T)$.

d. Data Sources

Data on weather is provided to the Target Acquisition Model by dividing the theater into 15 weather zones and drawing on weather data developed by the Rand Corporation from USAF records.

The line-of-sight parameters are set by dividing the theater into terrain and cover zones and inputting data from the CIA-developed National Intelligence Surveys.

Data on the ability of a sensor to acquire a target seems very incomplete, probably due in part to the difficulty of conducting field tests to measure this quantity. There are so many variables that can have an effect on target acquisition that it is inherently difficult and expensive to conduct controlled tests of a particular piece of hardware. The target acquisition equations, however, do have the virtue of allowing the rate at which targets are acquired to be easily changed and hence studied parametrically.

Elements of the Target Acquisition Model are summarized in Figure 4.

- Considers ground-based sensors and aerial sensors carried by fixed- and rotary-wing aircraft.
- Specific sensor types employed are visual observers, artillery radars, surveillance radars, conventional and infrared cameras, and side-lookeng airborne radars (SLARs)
- Three modes of sensor operation are modeled: standoff (fixed) mode, standoff (moving) mode, and a penetrating search mode to two depths--forward-area and deep-area search.
- The probability of target detection is a function of--
    - Number, location, and capability of sensors.
    - Number, location, and detectability of targets.
    - Environmental factors (e.g., terrain, vegetation, and weather).
- The target-acquisition model provides the expected number of targets acquired over a cycle to the nuclear model. These are the candidate targets for nuclear weapons.

Figure 4. TARGET-ACQUISITION MODEL

After the Target Acquisition Model has completed one of it's 4-hour cycles, model control sends to the Nuclear Model the status and location of active combat units, the number, type and location of acquired targets, the number of available nuclear delivery systems, and the specific combat conditions existing at the beginning of the first of three 4-hour nuclear cycles.

3. Nuclear Model

The purpose of the nuclear model is (1) to consider the information passed to it from the Target Acquisition model and along with user input or internal decision rules governing firing doctrine, to develop a weapon-target assignment list, and (2) to provide a rapid evaluation of the impact of nuclear weapons on the targets acquired. The level of accuracy attained and detail depicted is, insofar as possible, consistent with that considered by the other parts of the TACNUC model.

a. Assignment of Weapons to Targets

Basic to any attempt to model nuclear warfare is the method used to determine which nuclear weapons will be fired at which targets. It is well recognized that the decisions implicit in these determinations are the subject of considerable controversy. As a result, the examination of a wide range of deployment policies may in all likelihood constitute a major use of the model.

The greatest degree of flexibility one could have in examining alternative nuclear employment doctrine would be to have the user select each weapon for each target. This, of course, is unrealistic for anything beyond a manual war game. The other extreme, allowing internal decision rules to specify all weapons to all targets, does not appear to provide sufficient flexibility. Therefore, the approach taken in this model is to provide a basic framework for tailoring nuclear employment policy, which will allow the user to provide guidance on weapon employment, but still maintain the advantages of an automated simulation. Within this

structure it is hoped that, the user, by selecting appropriate parameters and values for a number of decision variables can come reasonably close to simulating any given nuclear employment doctrine.

Decision criteria for employing nuclear weapons is modeled by the establishment of a number of escalation states. Each escalation state has a set of rules that guide the engagement of targets in three target categories: battlefield targets, region targets, and COMMZ targets. A set of user supplied defining characteristics is required for each escalation state-target category combination as described next.

The input required to define a particular escalation state for battlefield targets, as an example, would include--

(1) A listing of allowable target types.

(2) A maximum depth beyond the FEBA to which targets by type may be engaged.

(3) A maximum fraction of targets by type which may be targeted during a cycle.

(4) A priority of target engagement by type target and range.

(5) A maximum allowable depletion of nuclear weapon reserves.

(6) The extent of permissible collateral damage.

By developing inputs for the above items, one can see how different strategies for nuclear weapon employment can emerge. In (1) the user admits or rejects certain types of targets as being of concern. In (2) the user specifies (for the battlefield targets at least) just how limited the engagements will be. In (3) the user specifies what is considered to be a necessary damage criterion for type targets. (Certainly 100% destruction is not necessary.) In (4) the user indicates what targets have priority of engagement by nuclear weapons, if detected. In (5) the user indicates what nuclear expenditure rates are acceptable within the nuclear policy being considered. Finally, in (6) the user specifies what collateral damage constraints are being considered.

The important thing to remember is that the user can limit each item as discussed, or can remove limits on any or all of the escalation state items. And can do this for each escalation state-target category combination. The total number of escalation states to be established is left open. It is a function of how many nuclear policy options the user wants to exercise.

The nuclear model is structured with three general types of escalatory stimuli that serve to initiate a transition from one escalation state to another. They are--

(1) A preplanned decision to make a preemptive strike,
(2) A response to a worsening tactical environment, and
(3) A response to the enemy's initial (or increased) use of nuclear weapons.

As before, certain specifications are required to quantify these general considerations. For the particular employment option being considered, the user must indicate which stimulus is operative and to which escalation state the model will move to. These items are required in order to generate an actual weapon-target assignment list for the escalation state-target category situation arrived at. The basic stimuli the user must input is defined in terms of the number of weapons delivered by the enemy into target areas in each target category.

A weapon-target assignment list, which can be developed in various ways, is maintained and updated when appropriate during the running of the model. The list contains information such as delivery system and yield (called a weapon type), weapon CEP by range, target type, and height of burst. The characterization of range and target location depends on whether the target is a fixed target or a mobile target.

For mobile targets (i.e., targets in combat divisions) weapon-to-target assignments are limited to numbers of weapons by type that are to be fired at type targets within a particular division zone. The target priority list referred to earlier is used now. The weapon types are ordered by increasing yield with ties broken

in favor of the more accurate weapon system. Thus, the preferred weapon type for a high priority target is that weapon type that will achieve the specified level of target damage for the given target type. The weapon type can be determined from user specified damage criteria (see escalation state) or may be specified explicitly.

For fixed targets such as airbases, supply depots, etc., the model ranks the airbases (that may be targeted) according to a weighted avarage of their numbers of aircraft and shelters. This ordering establishes a priority of targeting. The number of weapons delivered to each airbase depends on a particular targeting assumption. The targeting choices are to target one weapon on (1) the runway, (2) the most densely occupied aircraft parking area, or (3) each aircraft parking area.

Based on the prevailing escalation state, the numbers of targets by type that would be attacked are known, but consideration has not been given to firing constraints and weapon availability. Thus, the model calculates the number of targets of each type that are precluded, because of collateral damage constraints, from being attacked by the most preferred weapon type. The priority ranking of the preferred weapon type for firing at a given target type is defined. Then weapons are assigned to targets in order of decreasing priority. After the entire list of acquired targets has been considered once in this fashion, an additional iteration is performed to allow a certain amount of exploitation of second-best alternatives. The end product of this process is a matrix of weapon-target assignments indicating the number of rounds of a weapon type that are to be fired at given target types. These numbers of weapons are not ambiguous with respect to range, yield of weapon, or distance from FEBA to target since all the items considered are explicit attributes of weapon type and target type as previously defined.

b. Damage Assessment

The assessment of nuclear damage against military targets falls into two general categories: blast damage to weapons, equipment, and personnel and the cumulative effects of initial nuclear radiation against personnel. In each category effects against primary targets of interest and bonus damage to adjacent units will be evaluated.

All assessments are made in an expected value sense. That is, given assumptions regarding the distribution of targets, weapon CEP, target acquisition probabilities, and other such stochastic phenomena as are appropriate, a calculation is made of the mean damage level resulting from the nuclear weapon detonations. Primary targets are assumed to be either uniformly distributed in value with a specified radius or normally distributed with a specified variance. Target elements of bonus targets are assumed to be uniformly distributed over the fraction of the appropriate zone area which is not occupied by the primary target. For the case of multiple rounds being fired into a given division zone, the expected bonus damage level from blast to a particular target is compounded probabilistically assuming mutual independence between damage probability predictions for each burst. For the bonus target the probability of surviving each round is conditioned on the event that the target unit was not a primary target.

As the effects of radiation are additive in nature, a different device is required for their estimation. The basic approach is to maintain an estimate of the fraction of each battle unit which is in each of several cumulative radiation "states." The states correspond to cumulative dose levels or some appropriate surrogate such as the number of days remaining before becoming combat ineffective. As before, it is assumed that successive weapons are delivered independently. With this assumption the cumulative radiation state of personnel within a given battle unit is treated as a Markov process with the delivery of each weapon initiating a transition. For example, state j refers to those

people who have accumulated a level of radiation between RL(j) and RL(j+1). A person in state j is assumed to transition to state k if an amount of radiation between R2(j,k) and R1(j,k) is received. Of course, the probability of a person receiving levels of radiation between these limits depends on such factors as their current vulnerability to radiation, and specific characteristics of the weapon or weapons used against them. (It should be noted that even with the assumption of independence, the requisite Markov property that is assumed here does not hold precisely. However, it is felt to be a reasonable approximaion.

It should be stressed also that the effect of time which moves persons either closer to combat ineffectiveness or further away due to recovery depending on cumulative dose level is easily incorporated into such a framework.

A basic requirement for the calculations implied by this approach is an efficient means of determining the area covered by radiation of a *specified level*. This poses a problem since available radiation estimation algorithms calculate the radiation level at a *specified range* given appropriate weapon and target parameters. The approach used in the Nuclear Model to get around such a situation is to construct a subroutine which utilizes such an algorithm, along with a list of weapon yields, burst heights, protection factors, and various other effects assumptions to fit a number of curves. These curves, one for each yield, height of burst, and protection category combination estimate effective biological dose as a function of range, but in a functional form which is invertible. In particular, the form chosen is--

$$\ln(\text{dose}) = \frac{a_0 + a_1(\ln \text{range}) + a_2(\ln \text{range})^2}{b_0 + b_1(\ln \text{range}) + b_2(\ln \text{range})^2} .$$

This choice of approximating function was motivated by three factors--

1. Goodness of fit (5 parameters are available)
2. Invertibility
3. Ease of automation.

The third factor is important should a user wish to consider an alternative list of weapon or target characteristics or different effects assumptions.

Elements of the Nuclear Model are summarized in Figure 5.

After the Nuclear Model has completed it's first 4-hour cycle, the Target Acquisition Model is called again and completes it's second 4-hour cycle. Acquired targets are provided to the Nuclear Model for it's second cycle. This same process is then repeated for the third and final cycle.

When the final Target Acquisition-Nuclear Model cycle is completed, model control provides to the Ground-Combat Model the status of combat units updated with the results of the nuclear attacks. These results along with the close air support sorties from the Air-Combat Model are used to evaluate on a battle area-by-battle basis the outcome of the ground combat engagements.

4. Ground-Combat Model

The ground-combat model is that component of the TACNUC model that is used to assess the interactions of opposing ground combat forces. In particular, the ground model was developed for the following objectives--

1. To assess on a day-to-day basis the theater wide conventional ground combat activities that occur in a simulated war between two major powers.
2. To provide a vehicle wherein the various tactics and unit dispersion philosophies of a nuclear war environment may be examined, and
3. To assess the contributions and interactions of divisional sized combat units, along with the impact of tactical air units and nuclear weapons, on the outcome of the theater war.

The Ground-Combat Model, in a very aggregated fashion, simulates the combat processes that are felt would occur in a major, conventional theater war under the threat of nuclear intervention, as well as the combat activity during nuclear exchanges. Divisional

- Damage to targets is a function of
  - Type and size of target (i.e., hardness and size).
  - Target-location error, based on target-acquisition parameters.
  - Number, yield, and HOB of nuclear weapons fired.
  - CEP of delivery system as a function of range.
  - Blast and radiation effects of nuclear weapon.
- The targets considered are
  - Subunits of divisions, their personnel, weapons, and vehicles.
  - Airfields, SAM sites, and HQ units.
  - Nuclear delivery systems.
  - Supply depots and SASPs.
- The types of target damage assessed are
  - Military and civilian casualties.
  - Weapons, aircraft, and shelters damaged or destroyed.
  - Nuclear-delivery systems damaged or destroyed.
  - Nuclear warheads and tons of resupply destroyed.
- Employment of nuclear weapons is governed by
  - Escalation states (and escalation boundaries).
  - Escalation stimulii.
  - User-specified parameters for weapon employment.
  - Internal decision rules for weapon employment.

Figure 5. NUCLEAR MODEL

sized units are opposed in various battle areas across the theater and the daily ebb and flow of the line of contact between the forces (i.e., forward edge of the battle area, FEBA), is a major output measure of the model. This daily movement of the FEBA is a function of the ability of opposing forces to exact attrition on each other, and the inherent mobility of the divisional forces.

a. Combat Engagements and Postures

The types of combat engagements that occur are determined by the tactical mission of the opposing forces and where appropriate their defensive positions. The ground model recognizes tactical missions of attack, defend and delay, and prepared, hastily-prepared, or barrier defensive positions. The user specifies the location of each defensive position while all other areas in the theater are considered delaying positions. From these considerations the model dynamics generate the following six tactical postures: attack-delay; attack-defense of prepared position; attack-defense of hasty position; attack-defense of barrier position; breakthrough; and holding. All units, when not in an active battle area, are assumed to be in an inactive or reserve status.

For the initial combat cycle the side with the dominant force ratio (or as denoted by the user) is considered the theater attacker. However, the actual attacker in each sector is determined by the force ratio resulting from air and ground firepower being added to the battle. The tactical posture in each sector is determined by the FEBA location and in some instances by the combat effectiveness of the units. For example, if the Red force has a dominant force ratio overall but not in a particular sector, he may choose not to attack in that sector. If Blue chooses not to attack also, the tactical posture becomes a holding posture.

On subsequent combat cycles, selection of tactical posture for Red and Blue in each sector is determined by the current FEBA location and certain tactical rules. The general rules governing each days activities are stated as follows. If the flank between

sectors exceeds a specified critical length, the defending force with the exposed flank, if unable to reinforce with rear guard and flank security forces, assumes a delay posture to reduce the exposed flank. When the exposed flank for the attacking force exceeds a given length, and the attacker is unable to reinforce with rear guard and flank security forces, then forces in the adjacent sector begins the attack (if not already attacking) in an attempt to reduce the amount of exposed flank. If this cannot be done, the attacking force creating the salient must assume the holding posture. Another change in posture occurs when the attack of a prepared position is successful. In this case the combat engagement assumes a breakthrough posture with rate of advance in this posture holding for one combat cycle only.

b. Attrition and Movement

The ground model is structured also to show the impact of changes in various elements of the model. For example, the attrition assessments in each active battle area of each sector reflect, in an aggregated way, the processes by which ground combat weapons and close air support munitions interact in the combat environment. The strength of opposing forces and the quality and quantity of their weapons has a direct impact on attrition levels each period. The differences in combat deployment of each unit, brought about by the level of dispersion desired for each division because of the threat of nuclear fires, results in fewer units on-line than would exist in a more dense nonnuclear environment. The difference in logistic support can affect the combat effectiveness of units and hence their overall contribution to the battle. And finally, the tactical posture of the combat engagement affects the rate of personnel casualties and weapons losses, and along with terrain variations affects the ultimate rate at which the attacker advances.

Elements of the attrition process can be captured in a summarized version of its basic structure by the following four steps--

Step 1. The *allocated potential* of a particular Blue weapon or Blue air sortie against a particular Red weapon is determined based on Blues's *allocation of fire* against all Red weapons, the *number of Red weapons* available to be fired at, and the *individual potential* of Blue's weapon or air sortie against the Red weapon.

Step 2. The allocated potential values are translated into *individual weapon values* for each Blue weapon or air sortie to cause casualties and destroy weapons within the Red force by considering the *weapon value* destroyed when a particular Red weapon is killed by a particular Blue weapon or air sortie. This concept is referred to as the antipotential potential method for computing weapon value.

Step 3. By adding the values calculated in Step 2 over all Blue weapons in the immediate combat area produces the *total Blue weapon value* measured in terms of *Red weapon value destroyed.*

Step 4. Finally, *the ratio* of corresponding Red and Blue *weapon values* (considering ground weapons and close air support sorties) are used with empirical data such as force ratio relationships to produce Red and Blue personnel casualties and weapons destroyed.

The logic of the ground model assumes that FEBA movement also is a function of the force ratio just calculated for the attrition assessments. In addition, it is a function of the defender's posture, the type of terrain over which the battle is being fought, and the inherent mobility of the attacker's divisional sized units. The FEBA movement rate defines the distance that the FEBA location has changed in each sector during the course of a 12-hour combat cycle. It is synonymous with the advance of the sector attacker, and accordingly may add to or subtract from the cumulative distance the theater attacker has advanced. Considering that each of the 12-hour combat cycles consist of 8-hours of daylight and 4-hours of darkness, the movement rate tables normally used for either daylight or night conditions are adjusted accordingly.

c. Combat Effectiveness and Replacements

Combat effectiveness of a unit is a measure of the unit's current combat value relative to a standard or TOE combat value. The combat value is a function of the unit's weapons, personnel strength, and supply level. When shortages of people, weapons, or supplies occur in a unit, the effect is realized in a reduced combat value and hence a reduced measure of combat effectiveness of the unit.

Units that are sustaining attrition to people and weapons loss effectiveness, and at some level of loss, if not replaced, become combat ineffective and are withdrawn. The model logic inherent to model control contains options that allow the user one of three methods of handling replacements within divisional sized units.

One method is referred to as the individual replacement method where people, weapons, and (for the Nuclear Model) subunits are made available to be used as replacement resources for those divisions in need of replacements.

The second method, referred to as the unit replacement method permits no replacements to enter the combat division at any time while it is in active combat. When the division's effectiveness has been reduced to a predetermined level the division is withdrawn from combat and replaced with a unit of higher effectiveness.

The third and final method is arrived at by some combination of methods (1) and (2) as determined by user input.

Within the individual replacement method, personnel replacements are added to combat units in the active battle area as needed before addressing the needs of combat units in inactive battle areas. If the replacement pool has sufficient personnel to satisfy all replacement demands, nothing else need be done. However, if the demand from the active battle areas exceed personnel available, then personnel are replaced in proportion to each unit's demand.

Weapon replacements follow the logic of personnel replacements but are done on a weapon-by-weapon basis. Replacements will build a unit back to TOE values but will not exceed them. Weapon replacements actually come from two sources: a replacement pool that is supplies by sources outside the theater and a weapon repair pool that accounts for the recovery and repair of damaged weapons in or near the combat area.

Elements of the Ground-Combat Model are summarized in Figure 6.

When the Ground-Combat Model is completed, it provides to model control the status of combat units, updated with results of the ground combat and close air support attacks, and resultant movement within each battle area. At this point, model control switches to the Supplies Model for an evaluation of logistic resupply at both the combat unit-airbase level and at the theater supply depot level.

5. Supplies Model

The primary reason for considering supplies within the TACNUC model is to be able to evaluate their effect on the combat capability of forces. Since supplies are required by all elements of the force it is important to be able to model the way in which supply shortages will affect combat outcomes. However, it was necessary to build a fairly simplified model since it must operate within severe computer storage and running time constraints.

The European transportation system is represented by a 100 node, 250 arc network. The nodes represent theater supply nodes and airbases. The arcs represent transportation links between the nodes-road, rail, wateway, and pipeline all aggregated into one network. A single class of supplies is allowed and a single transportation network is considered. Each of the battle areas and the combat units and airbases it contains are assigned to a friendly supply node. When the enemy captures a supply node the friendly forces lose the use of that node and its arcs while the enemy gains their use. There are two special supply nodes at either

- Considers eight types of combat divisions deployed by battle areas within sectors
- Conducts (for each division) bookkeeping on personnel, weapons (by type), and supply level
- Assesses (on a theater-wide scale) ground combat in active battle-areas
- Considers six tactical postures:
  - Attack/delay
  - Attack/defense of prepared position
  - Attack/defense of hasty position
  - Attack/defense of barrier position
  - Breakthrough
  - Holding
- Determines personnel casualties and weapons losses from ground weapons and CAS sorties by using AntiPotential-Potentials (APPs) and force-ratio relationships
- Determines FEBA movement within each active battle-area using APPs, terrain, and force-ratio relationships
- Computes supply consumption of each division, on the basis of tactical posture
- Computes division effectiveness, on the basis of current personnel, weapons, and supply level
- Portrays (by means of six deployment-posture configurations) the transitioning of divisions from nonnuclear to nuclear postures

Figure 6. GROUND-COMBAT MODEL

edge of the theater representing notional input nodes through which supplies enter the theater. Of course, supplies can be input at any node, if desired, and so indicated by the user.

The flow of supplies among the supply nodes of the network is planned and may be redirected once each *major supply cycle* which is taken to be 3 or 4 days in length. A linear programming transportation algorithm is used to decide an efficient way to route supplies. The flow of supplies from supply nodes to combat units or airbases takes place every *minor supply cycle* which is 12-hours in length. Here demands on supply nodes from combat units or airbases are filled as much as possible from node inventories but no supplies shipments between nodes are initiated. However, shipments initiated within the major supply cycle may arrive at a supply node for this minor supply cycle.

In addition, supplies will be destroyed by enemy action. Supplies are destroyed in combat units by ground and air weapons, at airbases by air weapons, and at supply nodes by air weapons. A combat unit in short supply will find its combat effectiveness degraded.

Within a major cycle the goal is to distribute supplies from nodes with surplus supplies to those which are short of supplies. A surplus condition is assumed at a node only when it has adequate supplies to handle all the units assigned to it over the length of the major cycle. Certain rear supply nodes also attempt to hold inventories of supplies for units and airbases located forward of the nodes. These nodes might be thought of as major supply or logistic centers. Supplies which are shipped away from source nodes are assumed to leave at the start of the major cycle, they arrive at deficit nodes after a time lag which depends on the speed at which supplies are assumed to move. The transportation algorithm used to route supplies in a major cycle determines the shipping pattern which minimizes the total number of ton-kilometers shipped. It operates so efficiently that it represents a fairly small fraction of the total computer time required by the entire supplies model.

Once the pattern of shipments has been determined for the current major cycle, the events composing a minor cycle are repeated either 6 or 8 times until the next major cycle begins. At that time a new shipping pattern is set taking the current supply situation into account.

When the Supplies Model is completed, it provides to model control the updated status of all supply nodes in the network.

Elements of the Supplies Model are summarized in Figure 7.

Finally, model control, at the end of each 12-hour combat cycle, updates all of the ground combat and tactical air units in the theater. Resources of personnel, weapons, and aircraft that are either in the theater or are scheduled to arrive are used as replacement resources. The control routine also considers the updated forces, today's FEBA movement in each battle area, and the current combat postures as a basis for force deployments and combat actions for the next 12-hour combat cycle. Results of any combat cycle may exceed certain escalation state criteria that, in effect, directs the employment of nuclear weapons. Therefore, certain employment decisions are required now in order to reserve a given number of tactical aircraft for use during the next cycle by the Nuclear Model instead of being used as nonnuclear aircraft in the Air-Combat Model. After these actions are taken, the combat cycle begins anew with the Air-Combat Model.

- The flow of supplies through the theater is portrayed by a node-arc network.
  - *Nodes* represent ports, supply depots, and transportation centers
  - *Arcs* represent transportation links between the nodes
  - *Currently*, the theater comprises 112 battle areas, 95 supply nodes, and 244 arcs. Each battle area and the forces it contains are assigned to a "friendly" node. Airbases are also assigned to supply nodes. Supply nodes change sides as the FEBA advances and retreats.
- The supplies routing problem is handled as follows:
  - The model uses a transsipment algorithm to decide how supplies will flow in the network from surplus nodes to deficit nodes for each major supply cycle. A node is surplus or deficit depending upon the forces drawing on it and their stock of supplies, supplies stored at the node, and scheduled resupply from outside the theater.
  - Combat units and airbases are resupplied each minor supply cycle from their assigned node, on the basis of demand for supplies by the unit or airbase.
- Supplies are destroyed at various locations:
  - In battle areas by ground and air weapons
  - At airbases by airbase att ck sorties
  - At supply nodes by supply interdiction sorties
- Supply shortages reduce the combat effectiveness of combat units and degrade sortie capability of aircraft.

Figure 7. SUPPLIES MODEL

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An Introduction to IDAHEX

A MANEUVER-ORIENTED MODEL OF CONVENTIONAL GROUND COMBAT

by

Paul L. Olsen

PREFACE

IDAHEX is a theater-level computerized model of conventional ground combat capable of playing breakthroughs and encirclements. It operates on an area of war partitioned into hexagons. Its attrition process closely resembles IDAGAM's. It can determine the effects of user-input air strikes on the ground forces, but it cannot determine aircraft losses.

As of this writing, IDAHEX is nearly complete. It remains only to add procedures for moving supplies and replacements to where they are needed and to make some minor improvements in logic. The present version of the model has been coded in FORTRAN and is fully operational; tests have not exposed any bugs.

This is an interim report on IDAHEX. It does not cover all the model's features, nor does it explain any feature in complete detail. It is intended merely to bring IDAHEX to the attention of potential users, who might want to provide guidelines for the final development phase in order to assure that the end product will suit their needs as nearly as possible.

1. Directions in Modeling Ground Combat

Category 1 - free-form area of war.

EINFALL, TARTARUS, and DIVWAG fall in this category. The area of war is typically a rectangle, and units may be located anywhere in it. A unit's location is not a single point but a set of points--its zone of responsibility--which is required to be a rectangle in most models.

Advantages: Units can be located as precisely as desired, and their areas of responsibility are played explicitly. The structure of the area of war (AW) imposes no arbitrary restrictions on units' movements.

Disadvantages: Use of an unstructured area of war (AW) complicates model logic and communication with the user. Since units can be located anywhere in the AW, the rules for determining when units are engaged must be fairly complicated (which makes it difficult for the user to comprehend the course of the war). Typically, the engagement rules do not do justice to the complete freedom of movement the units enjoy; for example, most models in this category assume that a unit must stop when any part of its area of responsibility reaches the "minimum separation distance" from an enemy unit's area of responsibility.

Category 2 - axial AW

These are the ATLAS-type models. Current examples include IDAGAM, VECTOR, and the Lulejian model. The AW is sliced into axes (usually, in a stretch of military terminology, called "sectors"). A unit may only engage enemies in its axis and typically may only move across an axis boundary by entering a limbo area representing its side's COMMZ.

Advantages: The highly restrictive movement and engagement rules permit substantial simplifications of model logic. Since combat is confined to axes, each engagement has the same structure--a line of attackers moving against a line of defenders--so that modeling effort can concentrate on this one type of engagement. Also, confining movement and combat to axes makes it much easier to write a mission generator--a set of rules for deciding what units should do.

Disadvantages: Confining almost all movement and all attack to axes is too restrictive; very few major battles after World War I could be replayed in this structure.[1] Axial-AW models cannot play breakthrough and exploitation. Although one side can push the enemy back down an axis, the victors cannot cross over to adjacent axes to cut off enemy units. In particular, axial AW models cannot play encirclements. They assume that units always withdraw in time to avert encirclement. But there is no satisfactory basis for deciding how soon and how far they must withdraw; the usual devices of axial-AW models--front-to-flank ratios and FEBA smoothing--are arbitrary. In general, these models suffer from a lack of balance in modeling effort--most of the model logic is for determining attrition whereas there is very little logic for handling maneuver and none for handling attacks from multiple directions.

Category 3 - network AW

These models represent the AW as a network. Each unit is located at a node of the network. To get from one node to an adjacent node, it moves along the arc connecting them. The category includes MILITAC/MILISTRAC, TOTEM, and the war games of Avalon Hill, Inc., and Simulation Publications, Inc. The category can be subdivided according to the structure of the network. MILITAC/MILISTRAC accommodates any network the user selects. The

[1]The one exception I know of is the Battle of the Ishun Lakes in the Crimea, 1941.

other models mentioned above use networks based upon a partitioning of the AW. Partitioning the AW into congruent rectangles, locating a node in each, and then creating an arc between each pair of nodes whose rectangles are adjacent produces the ("rectangle-based") network implicit in TOTEM. Partitioning the AW into congruent hexagons, locating a node in each, and then creating an arc between each pair of nodes whose hexagons are adjacent produces the ("hexagon-based") network implicit in the Avalon Hill and Simulation Publications games.

Advantages: The AW structure is a compromise between the free-form and axial structures and enjoys some of the advantages of each. It admits more degrees of freedom in movement--four in a rectangle-based network and six in a hexagon-based network--than the axial structure while avoiding the free-form models' difficulties in establishing good engagement rules and communicating with the user.

Disadvantages: A structured AW always falsifies reality to some extent since it reduces the precision with which units can be located and compartmentalizes combat.

Despite the obvious inadequacies of axial-AW models, computerized modeling of warfare at the theater level has emphasized that category in recent years. Perhaps this is because applied mathematicians have dominated the field (attrition is attractive for mathematical exploration--maneuver is not). Perhaps it is because thus far efforts at network models have not met expectations. The network models identified above are all disturbingly primitive in their determination of attrition. But most disappointing is their failure to include enough equipment to take full advantage of the maneuver their AW structures permit. To handle encirclements, a model must be able to recognize when a defeated unit has no line of retreat and then destroy it; to play breakthroughs realistically, a model must evaluate engagements in small time increments so that when one side is defeated and driven out, the victor can occupy and proceed

immediately to his next objective (a company should not be able to delay a corps for an entire day). I know of no network model that meets both criteria.

IDAHEX was designed to be a computerized network model that maintains, as nearly as possible, a balanced effort between modeling attrition and modeling maneuver. It meets both of the criteria above. Its attrition process closely resembles IDAGAM's, and therefore, in contrast to the network models identified earlier, IDAHEX keeps track of the quantity of weapons each unit has, broken down by type. It also keeps track of each unit's supplies and personnel. The terrain, weather conditions, and barriers (e.g., rivers) in an engagement all affect attrition and FEBA movement. The model can calculate the losses caused by CAS and interdiction air strikes.

IDAHEX is modular in design to make it easier to change such thins as the attrition process, the way of calculating FEBA movement, and the way of calculating units' travel times.

2. The Structure of the Area of War

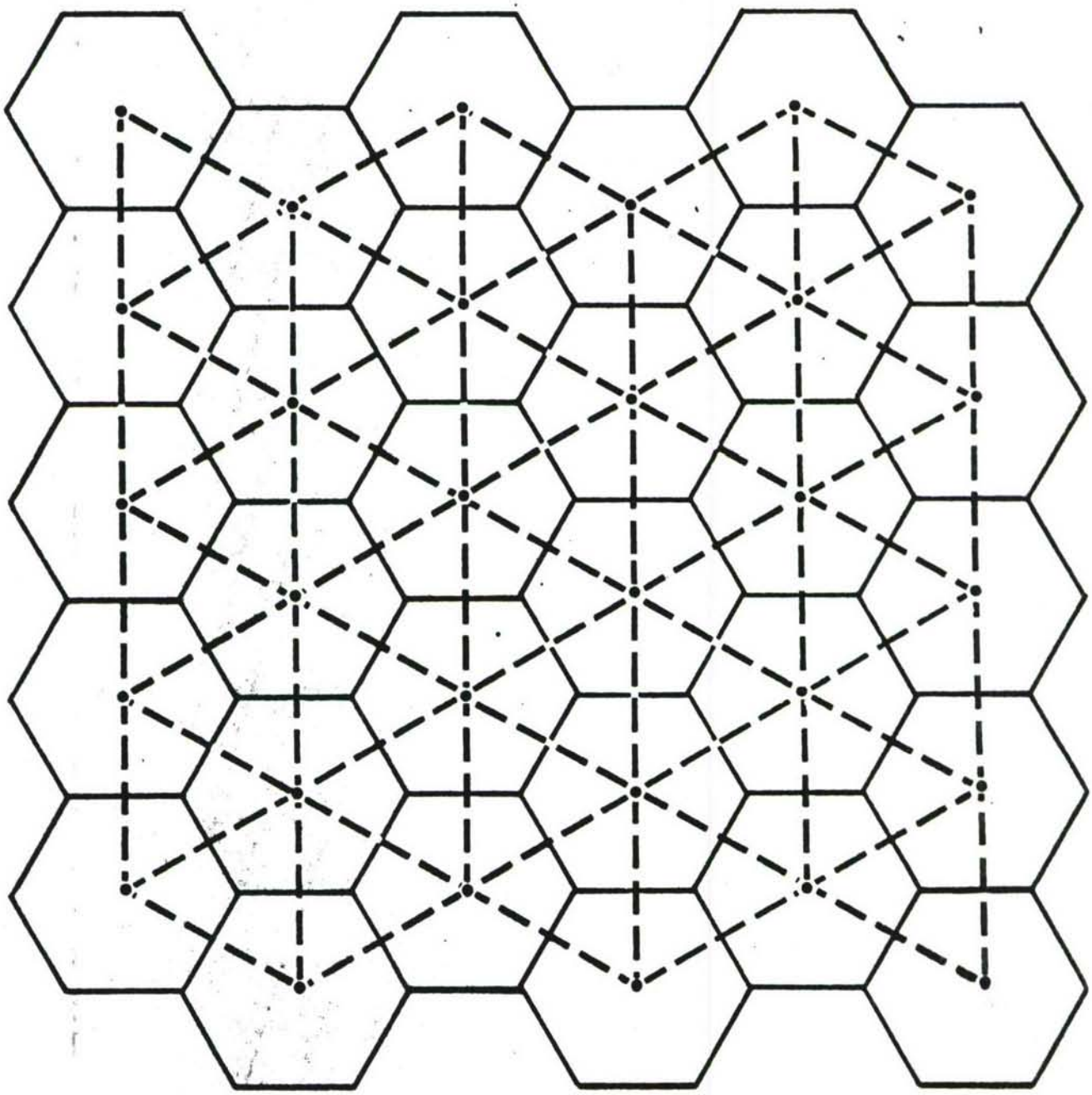
IDAHEX imposes a hexagon-based network on the AW. As noted in the preceding section, a partition of the AW into hexagons underlies the network. Fibure 2.1 depicts the partition and the network. Henceforth, the term "cell" will be used instead of "hexagon." The motivation is that the partition itself is transparent to the model--it is the structure of the network that counts. Starting with a partition of the network into congruent, hexagonal cells, one could deform the cells--changing their size and shape--without affecting the structure of the overlying network.

IDAHEX does require that each cell not on the AW perimeter have exactly six arcs incident to its node. Thus, there are two more degrees of freedom in movement than TOTEM allows, but not the flexibility of MILITAC/MILISTRAC, which allows the user to

FIGURE 2.1

STRUCTURE OF THE AREA OF WAR

RED SIDE



1-9-75-4

BLUE SIDE

specify any network he wants. The IDAHEX computer program exploits the structure of the hexagon-based network to achieve substantial efficiences in main storage utilization and computation time. None of these efficiencies would be possible if IDAHEX allowed an arbitrary network.

The rest of this section outlines inputs to IDAHEX that describe properties of the AW.

Each arc has a basic transit time, which reflects the length and terrain of the best route between the nodes incident to it but excludes the effects of any barriers. (There is exactly one arc between each pair of adjacent nodes; its basic transit time is assumed to be independent of the direction of travel.) Each arc also has a route type classification--an index number characterizing the terrain along the route corresponding to it (e.g., clear, roaded, muddy, densely wooded). Each arc also has a barrier type--an index number characterizing the type of barriers encountered on the route corresponding to it (e.g., no barriers, a river, a mountain range). The route type and barrier type classifications can be made as fine as desired; to illustrate, if an arc has two barriers, one barrier type can represent the combination. Route types and barrier types can be updated in the course of the war to reflect changes in trafficability conditions--e.g., nightfall, snow, mud, freezing of rivers and lakes. The time it takes a unit to move from one node to an adjacent node depends upon the arc's basic transit time, the route type, the barrier type, and the unit's type (defined in Section 4).

Each cell has an environment--an index number characterizing the conditions affecting combat, which are assumed to be uniform throughout the cell. Like the route type and barrier type, the environment can change, and, again, the principal reason for a change is a change in natural conditions, which includes nightfall and daybreak if the cycles (defined below) are short enough.

3. Temporal Structure

IDAHEX divides the war into cycles. The user specifies the length of a cycle, which remains constant throughout the war. At the start of each cycle, IDAHEX finds the demand for supplies in each cell and accepts updates to cell supplies from the input stream; a battle unit draws its supplies from the stocks of the cell where it is located. The model also accepts user-specified air strikes at the start of the cycle and finds the losses they inflict.

Each cycle is divided into one or more periods of fixed length. At the start of each period, units are assigned missions (explained in Section 4). Ordinarily, missions remain unchanged within the period, but tactical exigencies may precipitate alteration of some missions.

Each period is divided into one or more frames of fixed length. At the start of a frame, each battle unit draws supplies from the stocks of the cell where it is located. At the end of the frame, the model finds attrition and FEBA movement in each engagement. It also computes each battle unit's supplies consumption and draws down the unit's stocks accordingly.

Although some operations--those mentioned above--occur only at fixed intervals, most events in IDAHEX can occur at any time. For example, when a unit starts to move from one cell to an adjacent cell, the length of time needed to complete the move is computed exactly (from the arc's basic transit time, the route type, the barrier type, and the unit's type), and the unit's arrival time equals its departure time plus the length of time needed to make the move. Its arrival time is not rounded to coincide with the end of a frame, period, or cycle. Of the network models mentioned in Section 1, only MILITAC/MILISTRAC shares this feature.

4. Force Organization

The Red and Blue forces each consist of indivisible battle units. Each battle unit is described by its type, location, posture, objective, and resources. Of these, only its type can never change.

A battle unit's resources consist of materiel and personnel. Materiel consists of weapons and supplies. Weapons consist of ground-to-air weapons, which are defined to be those weapons that can be used only against aircraft, and the remaining weapons, termed "ground-to-ground" weapons. Both ground-to-ground weapons and ground-to-air weapons can be subdivided into an arbitrary number of types. The present version of IDAHEX can handle only one category of supplies and personnel, but it would be straightforward to reprogram the model to accommodate multiple categories of each.

Examples of battle unit types are "Red tank division," "Blue mechanized infantry division," "Blue mountain division," "Red airborne regiment." As noted in Section 2, a battle unit's type implies something about the length of time the unit needs to move from one cell to another (termed the "march delay" below). A unit's relative movement rate on an arc is a function of the arc's route type and the unit's type. The barrier delay is a function of the barrier type and the unit's type. Suppose a unit of type t wants to move from cell i to an adjacent cell, j. Let r be the route type of the arc (i,j) and let b be the arc's barrier type. Then the march delay (explained later) is $\alpha + \beta$, where

$$\alpha = \frac{\text{basic transit time of arc}(i,j)}{\text{relative\_movement\_rate}(r,t)}$$

$$\beta = \text{barrier\_delay}(b,t) \ .$$

The relative movement rate's dependence on route type and unit type is critical: an armored division is able to move faster (unopposed) in clear terrain than an infantry division, while an infantry division might be able to move faster in dense woods or mountains.

Each battle unit is, at any time, located in exactly one cell, and its location is defined to be that cell. Its location is not defined any more precisely--IDAHEX does not pretend to know where the battle unit is within that cell. One says that a unit occupies a cell if it is located there.

At any time, a battle unit is in one of six posture classes--

-1. destroyed
0. inactive
1. hold
2. disengage
3. march
4. attack.

A unit in the destroyed posture class was active in the AW at one time, which means that it once had a positive posture class, but has ceased to exist. It might have been reduced to a user-speficied minimal level of effectiveness in combat, which can happen because of a shortage of weapons, personnel, or even supplies, or it might have been defeated with no line of retreat. A unit in posture class 0 is not present in the AW but may arrive later, when it will get a positive posture class. A unit in the hold posture class is not trying to go anywhere, just to hold the cell it occupies. (It need not be under attack.) A disengaging unit is under attack and is in the process of breaking contact preparatory to moving to another cell. A unit in the march posture class is moving from its present location to another cell. A unit in the attack posture class is trying to occupy a cell--not necessarily occupied by the enemy--to which it has already marched.

Within each posture class there may be as many as ten postures. For example, the hold postures might be distinguished by willingness to yield ground in order to reduce attrition. The attack postures might be distinguished by desire to gain ground. The hold postures are numbered 10-19, the disengage postures 20-29, the march postures 30-39, and the attack postures 40-49.

When a battle unit has a positive posture, it also has an objective. One says that the unit is in a posture oriented to its objective. The unit's posture and objective together define its status. If the unit is in a hold posture (i.e., a member of the hold posture class), its objective is defined to be its location. If it is disengaging, its objective is the next cell to which it will move when it completes disengaging, which cannot be the cell where it is located. If the unit is in a march posture, its objective is the next cell it will occupy. If it is in an attack posture, its objective is the cell it is trying to occupy.

Everything that happens to a battle unit except attrition and resupply corresponds to a change of status. Since a unit's location is identified with a cell, its movement from a cell, i, to an adjacent cell, j, is not described by gradual progress along the arc between them. Rather, it's location continues to be cell i for a length of time sufficient to allow it to occupy j, and then its location changes instantaneously to j. If the unit starts in a hold posture, p(with $10 \leq p \leq 19$), at cell i, it must go through the following sequence of postures and objectives to get to j--

location	posture	objective
i	p	i
i	20	j
i	30	j
i	40	j
j	10	j

Notice that when a unit goes from one posture class to another, it first enters the standard posture in the new class; the standard postures are -10, 0, 10, 20, 30, and 40. After entering the standard posture in a new posture class, the unit may go to another posture in the same class.

Each change of posture, whether from a posture in one class to the standard posture in another class or from a posture in one class to another posture in the same class, incurs a delay time, possibly 0. Until the delay time has expired, the unit remains in its old posture. The time required to go from a disengage posture to posture 30, termed the disengagement delay, is the time required to break contact with the enemy if engaged. The time required to go from a march posture to the posture 40 with the same orientation as the march posture, termed the march delay, is the time required to transit the arc from the unit's location to its objective; the formula for it was presented earlier. The time required to go from an attack posture to posture 10 at the objective, termed the attack delay, is the time required to defeat any enemy battle units defending the cell; it is 0 if the cell contains no enemies in hold postures.

Before a battle unit located in cell i can attack enemy units located in cell j, it must march to j. This mandatory sequencing of posture changes may overestimate the delay in initiating the engagement, for the march delay depends upon the basic transit time of the arc (i,j), which assumes travel from a node located in the interior of i to a node located in the interior of j, whereas the defenders may actually be deployed on its perimeter. However, unless the cells are very big relative to the AW, the distortion is minor. This way of sequencing posture changes and computing delays spawns fewer complications than any alternative approach.

Every action by a battle unit corresponds to a change of status. An order is an instruction to a unit to change status. A mission is a sequence of orders; they must be executed in sequence As part of the mission, a snap time may be specified for each order; execution of an order commences at its snap time or after execution of the preceding order in the mission is completed, whichever comes later; execution of a mission's first order begins immediately if no snap time is specified for it.

IDAHEX acquires missions through a subroutine named OPS, called at the start of every period. The present version of OPS merely reads user-input missions, which is the form it must have to run IDAHEX in an interactive mode. To eliminate human intervention in the course of the war, it is necessary to use a version of OPS that generates missions internally. All the relevant information is available in OPS. The "only" difficulty is creating mechanical rules that generate good, realistic, or reasonable missions in the enormous variety of situations arising in warfare.

If IDAHEX is used interactively, so that a single user or two competing players input missions each period, writing missions must not be too tiresome. But even a simple battle unit action can imply a fairly long sequence of status changes: recall that in moving from a hold posture in one cell to a hold posture in an adjacent cell involves at least four status changes. Fortunately, a mission need not specify every order in the sequence. IDAHEX interpolates; given any mission, IDAHEX finds the shortest complete sequence of orders that contains the sequence specified in the mission. There is one restriction: the present version of IDAHEX requires that any mission designed to move a unit through a sequence of cells specify each cell, in sequence. Because of interpolation, a mission consisting of just one order can effect the following sequence of statuses for a unit located in cell i, adjacent to cell j--

location	posture	objective
i	p	i
i	20	j
i	30	j
i	40	j
j	10	j
j	q	j

where $10 \leq p \leq 19$ and $10 \leq q \leq 19$.

A unit need not have a mission. (A unit without a mission keeps the same status and location indefinitely unless the tactical situation forces a change.) And more than one unit can have the same mission. Units sharing a mission are termed a task force. All the units in a task force must have the same location at the start of the mission. At the end of the mission, they will have identical statuses and locations. The units in a task force always have the same status change delay. There are two reasons for organizing units into task forces: (1) it is often desirable in attacks to have units join the engagement and in disengagement to have units leave the engagement at the same time to prevent a fraction of the friendly force from coming under fire from the whole enemy force; (2) by reducing the number of missions it reduces computation time. Task forces can be disassembled at the start of each period when new missions are assigned.

5. Combat

Structure

An engagement begins when battle units from one side enter an attack posture oriented to a cell in which are located enemy battle units in postures 10 through 29, the defensive postures. The latter units are called the defenders. The attackers need not be colocated. An engagement ends when there are no longer any attackers (they broke off the attack or were destroyed) or no longer any defenders (they disengaged or were destroyed).

A stylized FEBA measures the territorial progress of the engagement. At the start of the engagement the FEBA position is 0; the attackers have arrived at the perimeter of the defenders' cell but have not penetrated. If the attackers are sufficiently strong relative to the defenders, the FEBA advances. Each cell has a user-specified depth, which never changes. The user also specifies a number α in the interval $(0,1]$ which is the criterion for deciding when the defenders must leave. If an engagement's FEBA reaches a depth equal to α times the cell

depth, the attackers are declared victorious and are allowed to occupy the cell--i.e., their attack delay ends, they go from posture class 4 to posture class 1, and their location becomes the cell under attack. At the same time the defenders must enter a disengagement posture and leave as soon as possible. One of IDAHEX's two tactical subprograms decides in which direction they leave. It may happen that they have no line of retreat, in which case they enter posture class -1. The process of deciding when a path of retreat exists is a bit too complicated to dwell upon here. It is not just a matter of checking whether the attackers occupy every cell adjacent to the defenders' cell since even if they do not their zones of control may still block the defenders' escape. Suffice it to say that the user can select parameters to indicate when, if ever, attackers are able to block retreat without their side's occupying all adjacent cells.

It is a little misleading to pretend that attackers fighting their way into an enemy-occupied cell are still located at their cells of origin. But it is necessary to keep track of where each attacker came from for several reasons, among them: (1) without knowing the direction from which each attack is coming, it is impossible to know whether defeated defenders have a line of retreat and, if so, in what direction; (2) an attacker might abort its attack, in which case it should end up located at the same cell it started from. And it is not unreasonable to continue calling an attacker's cell of origin its "location" until it is victorious, for the alternative is pretending that as soon as a unit enters an attack posture, it becomes colocated with the units it is attacking.

Ground-to-Ground Attrition Process

IDAHEX's attrition process extends the attrition process of the axial-AW model IDAGAM. The rest of this section outlines IDAHEX's attrition process, concentrating on aspects that differ from IDAGAM's.

The first step in determining losses in one frame of an engagement is finding the attackers' kill matrix, A, and the defenders' kill matrix, D. To keep things simple initially, suppose there are just one attacker and one defender. A_{ij} is the expected amount of the defender's materiel of type j killed in the frame by each (ground-to-ground) weapon of type i in the attacking battle unit. A_{ij} depends upon how weapons of type i allocate their fire, the attacker's posture, the defender's posture, the environment in the defender's cell (e.g., clear, wooded, sparsely urban, densely urban), the amount of time the defender has had to prepare his positions, and the barrier type of the arc between the attacker's location and the defender's. D_{ij} is the expected amount of the attacker's materiel of type j killed in a single frame of the engagement by each (ground-to-ground) weapon of type i in the defending battle unit.[1]

The case of multiple attackers and multiple defenders will be discussed later. For now, suppose that kill matrices A and D have been computed for an attacking force and a defending force that may each contain more than one battle unit. Again, A_{ij} is interpreted as the expected amount of the defending force's materiel of type j killed in one frame of the engagement by each weapon of type i in the attacking force. D_{ij} is interpreted analogously.

The kill matrices, A and D, imply a value for each weapon via the antipotential potential method. Multiplying the value of the attacking force's ground-to-ground weapon j by the number of weapons of type j in the attacking force and summing over

[1]Notice that the attacker's vulnerability depends upon the environment at the defender's location, not the attacker's. The rationale is that, under the assumption that the environment in a cell is uniform, once the attacker's maneuver units have achieved any penetration they are in the same environment as the defender. However, a compromise would be very easy to implement: the attrition procedure could assume that the attacker's environment is the environment in the cell where he is located until the FEBA has penetrated to a specified depth, and then the attacker's environment is the same as the defender's.

each j gives the attacking force's ground value. Likewise, the values of the defending force's ground weapons determine the defending force's ground value.[1] The ratio of the attacking force's ground value to the defending force's ground value is termed the ground force ratio. Together with the forces' postures it determines what fraction of its ground value the attacking force loses, call it α, and what fraction of its ground value the defending force loses, call it β.

Let m be the number of ground-to-ground weapon types in the attacking force, and let n be the number of ground-to-ground weapon types in the defending force. Let w^A be the vector whose i^{th} component is the quantity of weapons of type i in the attacking force. Let w^D be the vector whose j^{th} component is the quantity of materiel of type j in the defending force. Let v^A be the vector whose j^{th} component is the value of each weapon of type j in the attacking force. The kill matrix D implies that the attacking force's loss of value as a fraction of its value at the start of its frame is

$$\hat{\alpha} = \frac{\sum_{j=1}^{m} \left(\sum_{i=1}^{n} D_{ij} w_i^A \right) v_j^A}{\sum_{j=1}^{m} v_j^A w_j^A} .$$

The quotient $\alpha/\hat{\alpha}$ is used to scale the losses implied by D--i.e., the actual loss of material of type j by the attacking force is computed as

$$\frac{\alpha}{\hat{\alpha}} \sum_{i=1}^{m} D_{ij} w_i^A .$$

When the losses are scaled that way, the attacking force does indeed lose the fraction α of its value at the start of the frame.

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[1] Actually, each force's ground value is computed as the sum of the ground values of the battle units composing it, and the model reduces the ground value of a battle unit if it is short of supplies or personnel.

An analogous procedure determines the defender's losses.

It is difficult to get a reliable estimate of the rate at which weapon i would kill weapon j in an actual engagement. But one may be able to estimate relationships among the elements of D without knowing the magnitude of any element reliably: one may estimate that a tank will kill twice as many enemy tanks as artillery pieces without knowing how many tanks or artillery pieces it will kill. Thus, the losses implied by A and D need to be scaled, and the procedure described above appears to be a satisfactory way of doing it.

A kill of one item of materiel of type j by a weapon of type i implies an expected number of personnel casualties. Thus, a battle unit's actual losses of materiel determine its loss of personnel.

Construction of A and D was explained earlier for the case in which there are only one attacker and one defender. Suppose, in contrast, that there are multiple attackers and defenders in an engagement. For each attacker-defender pair, the rate at which the attacker's (ground-to-ground) weapon i can kill the defender's materiel j depends on the attacker's posture, the defender's posture, the environment, the defender's preparation time, and the barrier type of the arc between the attacker and the defender. It is not necessarily the case that all attackers have the same posture or that all defenders have the same posture. Defenders may have arrived in the cell at different times and, therefore, enjoy varying degrees of preparation. If the attackers do not all have the same location, the barrier types of the arcs along which they are attacking may differ. Thus, the rate at which weapon i can kill materiel j may be different for each attacker-defender pair.

Given that A and D are to be used in the antipotential potential method, here is the ideal way to construct A and D when there are multiple attackers or defenders. Group the attackers into "attack equivalence classes" such that each battle unit in

an attack equivalence class has the same posture and is attacking along an arc with the same barrier type. Group the defenders into the "defense equivalence classes" such that each battle unit in a defense equivalence class has the same posture and degree of defensive preparation. Create a distinct set of ground-to-ground weapon types for each attack equivalence class and for each defense equivalence class--that is, a weapon of type j belonging to a battle unit in one equivalence class is now considered to be a different type than a weapon of type j belonging to a battle unit in another equivalence class. Expanding the number of weapon types that way makes the definition of the rate at which one type of weapon kills another unambiguous. The expanded kill matrices A and D are used as before to compute losses.

Unfortunately, the expanded A and D may be so much bigger that they occupy too much main storage and that computation of the weapon values by the antipotential potential method takes too long. Therefore, IDAHEX does not expand the kill matrices. Instead, it computes A_{ij} as a weighted average of the i-j kill rates for the various attacker-defender pairs; it computes D_{ij} analogously. The weighting is done in such a way that the following property holds: if there is just one equivalence class of attackers and one of defenders, the ground force values are the same as would be obtained by using the "ideal" procedure.

Air Strikes and FEBA Movement

At the start of each cycle IDAHEX accepts air strike selections from the input stream. To make an air strike the user (or player) specifies--

- which side (Red or Blue) is making the strike
- which cell is the target
- whether the strike is in close support of engaged battle units (if not, the strike is termed "interdiction")
- how many aircraft of each type participate (the air strike composition).

All losses inflicted by an air strike are assessed immediately. If the air strike is CAS, the losses of ground-to-ground weapons are recorded for use by the engagement procedure, which operates every frame. The reason is that CAS ought to affect FEBA movement just as ground fire does. Recall that each side's ground value in an engagement is computed as the inner product of its vector of ground-to-ground weapons with the vector of their values. A side's air value is computed in the same way--

- Let a_j be the number of type j ground weapons belonging to enemy battle units in the engagement killed by friendly CAS in the current cycle.
- Let v_j be the value of each enemy weapon of type j.
- The air value is $\sum_j v_j a_j$ divided by the frame length.

Division by the frame length is necessary to spread the effects of the CAS evenly over the cycle. The alternative (which would be easy to implement) would be to let CAS impact the engagement only in the first frame of the cycle.

The rate of FEBA movement in one frame of an engagement is a function of the attackers' postures, the defenders' postures, and the combined force ratio, which is

$$\frac{\text{attacker ground value + attacker air value}}{\text{defender ground value + defender air value}}.$$

In contrast to IDAHEX, IDAGAM uses the combined force ratio instead of the ground force ratio to determine ground force losses and does not independently assess losses caused by air strikes. Revising IDAHEX to use the IDAGAM procedure would be fairly simple but inappropriate. For the IDAGAM procedure implies that the losses inflicted by an air strike depend upon the ground force ratio, which can lead to strange results when the ground force ratio is very large or very small. In the case of an interdiction strike, the IDAGAM procedure would fail completely since there would be no way to compute the values of the target weapons. It seems better to regard air-to-ground fire as "exogenous fire," to borrow a term from INSURGE II.

The munitions load of each type of aircraft is part of IDAHEX's input data, and therefore the last item above determines how much of each type of munition is fired into the target cell. The input data also control the allocation of each air-to-ground munition's fire among resources on the ground. The user can define the aircraft munitions loads and the allocation of fire so that through his selection of the air strike composition a player can destroy ground resources selectively, by type.

It is reasonable to suppose that an aircraft can distinguish between a tank and an artillery piece, so it is nice to have the capability just mentioned. It is not clear that an aircraft can always distinguish one enemy battle unit from another, even if conditions are perfect. IDAHEX assumes that two battle units on the same side located in the same cell are distinguishable for the purpose of an air strike if an only if: (1) one is engaged and the other is not; or (2) neither is engaged but they are in different posture classes. When a player orders an interdiction strike, he assigns a priority to battle units in each posture class. The strike's fire is divided among the enemy battle units located in the target cell which have the highest priority posture class, and no others. If the highest priority posture class is 1, the supplies located in the cell but exogenous to the battle units are also hit. If no enemy battle units are found in the target cell and there are no supplies there, the air strike is wasted.

The materiel losses caused by a given air-to-ground munition fired at a battle unit depend upon the munition's allocation of fire among the various types of materiel, the battle unit's posture, and its environment. Remember that cell environments can change, to reflect, for example, changes in visibility conditions.

Each kill of an item of material type j by air-to-ground munition i implies a certain number of personnel casualties. Thus, a battle unit's materiel losses determine its personnel loss.

6. Other Aspects of IDAHEX

This section mentions some aspects of IDAHEX that are not discussed in any detail in this report.

Recall that the rates at which an attacker's ground-to-ground weapons kill the defending force's materiel depend upon the barrier type of the arc along which he is attacking. This barrier effect ceases once the FEBA has penetrated to a prescribed depth.

Recall that the rate at which a defending force's materiel can be killed depends upon the length of time he has had to prepare his defense. This effect ceases when the FEBA penetrates to the depth of the defense, which depends upon the total area of the defending force (the sum of the defenders' areas of responsibility) and the number of directions from which it is being attacked.

A realistic ground combat model should show variation in the intensity of combat and occasional lulls. Lulls occur in IDAHEX in the interval between a defender's disengagement and his attacker's pursuit and re-initiation of the attack. To get variation in the intensity of combat in the course of an engagement, IDAHEX uses the concept of tactical involvement. As the attackers penetrate the defenders' cell, an increasing fraction of the hostile forces become directly involved in the combat. The fraction reaches 1 when the attackers have penetrated to the depth of the defense.

If IDAHEX is not used in an interactive mode, CAS might be directed to a cell where there is no engagement. IDAHEX diverts the strike to targets of opportunity in the cell.

Because IDAHEX permits several degrees of freedom in movement and lets Red and Blue act simultaneously, several conflicts can arise. For example, hostiles can arrive at the same unoccupied cell simultaneously; while a battle unit is marching or attacking, enemies may attempt to occupy its location; battle units may try

to march in a direction from which they are being attacked. IDAHEX's logic resolves these conflicts.

Modifying the model's WAIT subprogram, which computes status change delays, makes it possible to play airborne and amphibious operations.

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STRUCTURE AND ORGANIZATION OF VECTOR-1

Alan F. Karr

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1. INTRODUCTION

This paper is a description of the structural and organizational characteristics of the Vector-1 combat simulation, together with some comments thereon. It is intended as a companion to [2], which is a rather detailed description of the attrition calculations used in the model. This paper contains no material on attrition.

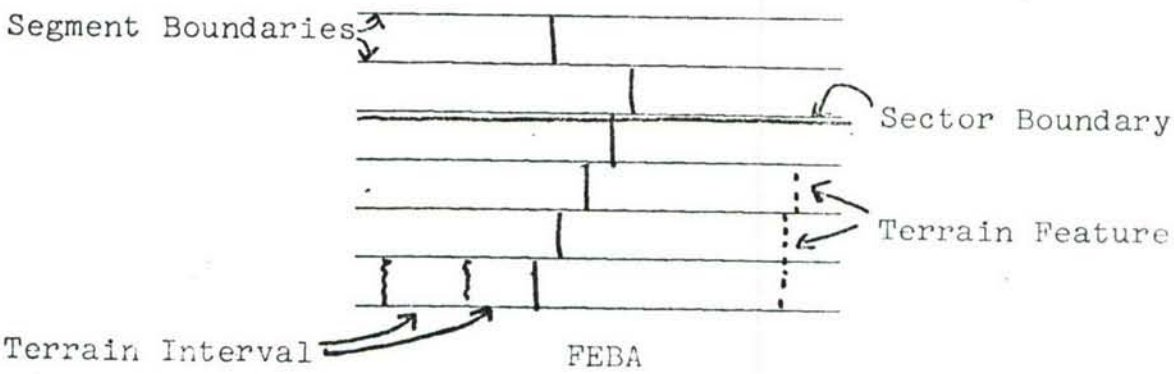
Vector-1 is a computerized, iterative, deterministic simulation of mid-intensity, theater-level, ground-air combat. The report [1] on which this paper is based states that the model is intended "to provide information useful in making net assessments and general purpose force tradeoff analyses." The main characteristics of combat the model purports to represent are terrain, firepower, organization, supply consumption, movement, and activity assignment. Not all of these are, we feel, modeled equally successfully. In general, the greatest attention appears to have been devoted to the model of "assault on a hasty defense." Indeed, on the basis of the genesis of this model one is tempted to conclude that a theater-level structure has been appended to a battalion-level combat model (the Individual Unit Action Model) in a somewhat hasty and haphazard manner. There is not a consistent level of assumptions throughout the model: those concerning ground combat are much more detailed, and (evidently) less restrictive than the others. This is particularly true for attrition computations, but is true also for terrain, movement, and organization. Perhaps the model might be viewed not as an overall theater level model, but instead as a detailed model of ground combat within a larger context, with the theater-level superstructure maintaining external inputs at roughly correct

values. But even in this interpretation the results of the model and its ability to discern the effect of minor variations in the plethora of detailed inputs to the ground combat portion of the model should be viewed with caution. The overall effect of disaggregation of one part of the model, within the context of the assumptions made in the other parts, is unclear. Without further evidence--because of the inconsistencies so introduced--there is no reason to believe this disaggregation is of more than limited value.

An interesting and positive feature of the model is the inclusion of "tactical decision rules," discussed in more detail in Section 5, by means of which the user can define a number of decision variables as functions of any state variables. Any function which can be programmed into the computer is acceptable, giving the user great flexibility in modeling behavioral and organizational aspects of combat (which, despite their obvious importance, are neglected by most other models). Whether any effort has been devoted to the development of large numbers of realistic rules is, of course, quite another matter. But at least the potential flexibility is impressive.

2. GEOGRAPHY AND MOVEMENT

Vector-1 attempts to be more explicit and detailed about geography than some other models and succeeds to a certain extent. The geographical representation is basically a conventional one, as indicated below.



The territory assigned to each side is divided into eight sectors, each of which contains a battalion task force (or comparable unit). Sector boundaries must be the same on both sides of the piecewise linear FEBA which separates the two opposing forces. Parallel to the FEBA each sector may be divided into terrain intervals representing up to twenty-five types of terrain (five levels of visibility and five levels of trafficability). The effect of these different types of terrain is on movement rates and inputs to the calculation of attrition rate coefficients. Every sector is subdivided into segments (the same on both sides), each of which contains one battalion and is conceived as being 2-8 kilometers wide. All ground combat effects are computed on a per-segment basis; in this respect there is no interaction among segments. Rear regions also exist.

Also parallel to the FEBA and of sector (or more) width are terrain features, namely rivers, urban areas, and one user-defined terrain feature. While these features provide, in a strict sense, more detail within the model, their overall effect on the results is minimal and appears essentially only through effects on force movement. Attrition incurred in interactions at such features is stated in the report to be so slight as to justify being modeled solely by user-input tables.

Force movements are determined by force availability and tactical decision rules (see Section 5). Movement of the FEBA is computed from a decision to move (a decision variable computed using one of the tactical decision rules) and movement rates supplied as inputs. The amount of movement may also depend on decisions to disengage and on the type of terrain. Smoothing of the FEBA is accomplished by certain of the tactical decision rules.

3. RESOURCES AND RESOURCE ALLOCATION

Vector-1 models the following resources:

A. Maneuver force weapon systems
   - 2 tank systems
   - 3 antitank weapons
   - Infantry on foot with rifles
   - Infantry mounted on armored personnel carriers
   - Infantry with machine guns
   - Infantry with area fire weapons
   - Minefields

B. Artillery forces (1 weapon class)

C. Attack helicopters (1 weapon class)

D. Air defense artillery
   - Long range
   - Short range

E. Tactical aircraft
   - 7 aircraft types
   - Shelters

Provision is also included for personnel not in maneuver units (e.g., those in rear areas). In general, weapons systems are counted explicitly but personnel are not. Each weapons system has associated with it a certain number of personnel (for purposes of counting force strengths), some, but not necessarily all, of whom are killed if the weapons system is destroyed by the enemy. So far as we can determine this is the only way personnel casualties can occur in Vector-1.

The following supplies can exist at the segment, sector, and theater levels (with some restrictions):

Ammunition by weapon type
Mines
10 types of aircraft ordnance
Aviation gasoline and related supplies
1 other class of supplies.

Supply transfers and allocations are effected by the tactical decision rules; consumption of supplies is a linear function of resource usage. Supply shortages degrade force performance only by means of activity choice (again using tactical decision rules), not by changing the values of effectiveness parameters.

Sector- and theater-level reserve forces are modeled; replacements on both individual and unit bases are permitted. Assignment of replacements is also governed by tactical decision rules.

4. INTERACTIONS

The following is a list of the combat interactions modeled in Vector-1.

A. Ground combat between maneuver units
   - Assault on a hasty defense
   - Advance by one side/delay by the other
   - Pursuit by one side/withdrawal by other
   - Relative inaction
   - Crossing of urban area (or river, or other terrain feature)
   - Bypassing of urban area (or other terrain feature)

B. Artillery roles
   - Counterbattery fire
   - Maneuver unit support
   - Deep support

C. Tactical aircraft missions
   - Airbase attack
   - Combat air support
   - Air defense suppression
   - Interdiction
   - Escort
   - Air defense
   - 1 user-defined rear area mission

As previously noted, the only ground combat activity not modeled by means of user-input tables is that of assault on a hasty defense; the methdology used to model this activity is described and commented upon at length in [2], as are the attrition calculations for other interactions.

Air defense artillery function only in that role and attack helicopters can be used only in support of maneuver units at the FEBA.

5. TACTICAL DECISION RULES

As should be clear from the preceding sections the tactical decision rules play a crucial role in the Vector-1 model. The basic purpose of the rules is to set the values of decision variables (i.e., to choose among alternatives) based on the current values of certain of the state variables (i.e., force strengths and positions, reserve levels, supply levels). Any programmable function is acceptable as a tactical decision rule; the rules must incorporate suitable safeguards against patently impossible actions, such as assignment of more forces than exist. The general areas in which the rules function are allocations of resources to sectors, retirement and commitment of maneuver units at the FEBA, allocation of reserve resources, the decision move at the FEBA (either to seek to advance or to disengage and withdraw) and all activity assignments.

Specifically, tactical decision rules are used in the following contexts for each time period:

(1) assignment of newly deployed aircraft to sectors;

(2) assignment of newly deployed helicopters to sectors;

(3) assignment of newly deployed maneuver units, personnel and weapons systems to sectors;

(4) determination of forces to be retired from the FEBA to reserve status;

(5) commitment of reserve units to the FEBA and determination of strength at which they are committed;

(6) assignment of individual replacements to segments;

(7) determination of sector intent variables (e.g., seek to advance, seek to hold a defensive position);

(8) setting of segment plans;

(9) determination of segment activity (one of the types of ground interaction listed in Section 3);

(10) assignment of aircraft to missions;

(11) determination of number and allocation of artillery rounds;

(12) assignment of helicopter sorties to segments;

(13) choice of data base for certain calculations (based on type of infantry, movement, ...);

(14) minefield assignment;

(15) determination of occurence of attacks on hasty defense, calls for support fire, disengagement (possible results: defender breaks off, defender calls for artillery support or air support, no action; similar choices for attacker); and

(16) FEBA smoothing within sectors and sector-to-sector.

As previously noted, these rules impart great (potential) flexibility and power to the model, which have probably not yet been fully exploited. They also serve the laudable purposes of collecting in one place a number of related inputs and problems, and of forcing upon the user an awareness of the assumptions underlying this portion of a combat simulation. With Vector-1 the user can fairly easily make changes not easily made in other models and can ascertain the effect of changes in behavioral and organizational factors that are possibly more important to the eventual outcome of a combat than things such as force composition and strength (at least over the ranges ordinarily considered). The user who carefully constructs his own tactical decision rules has a much better understanding of Vector-1 than he does of a model to which he supplies only numerical inputs.

Possible disadvantages are that the user may be ill-prepared to construct these rules; it may well be true that determination of a preferred form for each rule is the responsibility of the model-builder. He should at least make recommendations, of which there are none in [1], but which presumably exist. Finally, there is the possibility that these rules have so much

influence on the results of the model (particularly if they are ill-chosen) as to render it nearly useless for its stated purposes.

On the whole, however, the idea seems very commendable and, if not abused, rather desirable and effective.

6. INPUTS AND OUTPUTS

As inputs Vector-1 requires quantitative force performance data, initial resources and time-phased resource arrivals, and the tactical decision rules. The main outputs are daily and cumulative weapon system losses and personnel casualties, classified by type and by cause; supply levels and consumption, both daily and cumulative, and numbers and locations of currently surviving resources, including reserves. A wide range of secondary outputs are also available.

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Institute for Defense Analyses
Project 23-44
Working Paper WP-1
May 1975

ATTRITION PROCESSES IN VECTOR-1

by

Alan F. Karr

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I. INTRODUCTION

This paper is a summary of the attrition methodology in the Vector-1 theater battle model [2]. It is largely descriptive, but contains also critical remarks and some suggested alternatives.

II. ATTRITION PROCESSES

1. Ground-to-Ground

The main attrition computation, for battalion-level engagements at the FEBA, is based on a mixed-mode heterogeneous Lanchester equation of the form

$$\Delta n_i = \left(\sum_j A_{ij}(n,m)m_j\right)\Delta t \quad , \tag{1}$$

where

n_i = number of target weapons of type i
m_j = number of shooting weapons of type j
Δt = time interval,

and where the A_{ij} are rates of attrition per unit time and are of the following forms:

i) If shooting weapons of type j are impact lethality weapons, then

$$A_{ij}(m,n) = a_{ij}$$

for some constant a_{ij} which can depend on range and whether the shooter and the target are stationary. Such terms of the equation are of Lanchester-square form.

ii) If shooting weapons of type j are area fire weapons, then

$$A_{ij}(m,n) = b_{ij}n_i$$

for some constant b_{ij}, giving a Lanchester-linear form of attrition. The b_{ij} also can depend on range and whether movement is occurring.

One can rewrite (1), somewhat more intuitively, as

$$\Delta n_i = \Big(\sum_{j:\ \text{type } j \text{ is impact lethality weapon}} a_{ij} m_j\Big)\Delta t + n_i \Big(\sum_{j:\ \text{type } j \text{ is area fire weapon}} b_{ij} m_j\Big)\Delta t \quad . \tag{2}$$

Whether a given type of weapon is impact lethality or area fire is evidently independent of the type of target weapon.

Some rather sophisticated mathematics is used in the computation of the attrition coefficients a_{ij} and b_{ij}, which are updated each time period and are computed by the model from physical data concerning weapons (acquisition times, lengths of visible periods, kill rates, search cutoff times, serial or parallel acquistion, ...) as well as time-evolving quantities (range, movement, tactical decision rules, ···) and fixed data within the model (terrain features). The only computations which really need to be carried out within the model are those involving range, movement, decisions, and terrain. These are performed by using tables giving attrition rates as functions of the above variables. The sophisticated calculations can be performed externally. While such sophistication (limit theorems for semi-Markov processes, e.g.) is, in principle, desirable (provided the underlying assumptions are deemed acceptable) and is certainly a better way of computing the attrition coefficients than some others that have been used, it should be clearly understood that the detailed assumptions and complicated mathematics apply only to the calculations of attrition coefficients and <u>not to the model</u> (i.e., (1)) <u>itself</u>. The assumptions underlying the model are those of heterogeneous Lanchester combat; cf. [5]. In particular, the proper distinction between square law/linear law and point fire/area fire remains unresolved. It also seems that the model is so highly aggregated that sophisticated calculation of attrition coefficients may be rather unproductive, and perhaps

misleading in the sense that someone might be led to believe that the model is capable of resolving the effects of even very gross variations in parameters such as "mean length of visible period" or "time spent acquiring some targets and selecting one to attack."

Personnel losses in combat at the FEBA are computed from weapon system attrition in the following manner

$$\Delta p = \sum_i c_i \Delta n_i \tag{2}$$

where

Δp = personnel attrition

c_i = number of personnel killed when one type i weapon is destroyed.

The c_i are user-specified inputs to the model. Similar calculations apply to personnel losses in the other interactions discussed below.

Attrition to units at the FEBA due to artillery is computed in the following manner

$$\Delta n_i = n_i(1 - f)^m \ , \tag{3}$$

where

m = number of artillery rounds fired

f = fraction of targets destroyed by one round.

The "kill fraction" f, which may alternatively be interpreted as the probability that a single round kills a particular target, depends on the type of target and type of artillery. Equation (3) is simply a multiple shot binomial equation. Why artillery fire is believed to be better described by (3) than by (1)--after all, an artillery piece is the epitome of an area fire weapon--is never stated in the report. Underlying (3) is the questionable assumption that different artillery pieces operate independently of one another. Of course (cf. [3]) this assumption also underlies (1).

For rear area attrition due to artillery the equation used is

(4) $$\Delta n_i = mk ,$$

where

m = number of rounds

k_i = number of targets of type i killed per round.

The same equation is also used for counterbattery fire; the k_i are inputs to the model and depend on the type of shooting weapon. As with equation (3), no justification for this (rather clearly) unnecessarily approximate equation is offered in the report. It would seem preferable to use (3) or even an approximate form thereof, such as

(5) $$\Delta n = n(1 - fm),$$

rather than (4).

2. Air-to-Air

An attacking air group contains both attack aircraft and escorts and is vulnerable first to the opposition's interceptors. Escorts must attack interceptors on a one-on-one basis. Thus the probability that a particular type i escort engages some type j interceptor is

$$q_{ij} = p_{ij} \min\{\frac{1}{E},\frac{1}{I}\} I_j ,$$

where

I_j = number of type j interceptors,

I = total number of interceptors (of all types),

E = total number of escorts,

p_{ij} = probability of engagement given decision to engage.

Consequently, attrition to type j interceptors is

(6) $$\Delta I_j = I_j \sum_i E_i k_{ij} q_{ij}$$

and that to type i escorts is

(7) $$\Delta E_i = E_i \sum_j I_j k'_{ji} q_{ij} ,$$

where

E_i = number of escorts of type i ,

and k_{ij}, k'_{ji} are probabilities of kill given engagement. By analogy with process L3 of [3] we believe that (6) and (7) are of Lanchester-linear form, with modifications to account for one-on-one duels.

These equations have some rather unusual properties in special cases, however. Suppose E>I so that

$$q_{ij} = p_{ij} \frac{I_j}{E}$$

for all i,j. In this case (6) becomes

$$\Delta I_j = I_j \sum_i E_i k_{ij} p_{ij} \frac{I_j}{E}$$

and in particular, if the k_{ij} and p_{ij} are independent of i (with j fixed), we obtain

$$\Delta I_j = k_j p_j I_j^2 ,$$

which is certainly an unusual equation. Moreover, in all cases either (6) or (7) has the potential to reduce to this form.

A possible alternative to this equation would be the barrier penetration model proposed in [1], which seems to handle one-on-one engagements more sensibly.

The remaining

$$I_j^{(1)} = I_j (1 - \sum_i E_i q_{ij})$$

interceptors of type j not engaged by escorts proceed to engage the attack aircraft, again only by means of one-on-one duels. The number of attack aircraft engaged is thus

$$A = \min\{\sum_j I_j^{(1)}, A_0\},$$

where

A_0 = total number of attack aircraft (all of which are of one type in any given encounter).

The number of interceptors of type j killed by the attack aircraft is then computed according to the equation

$$\Delta I_j^{(1)} = p_j \frac{I_j^{(1)}}{\sum_k I_k^{(1)}} A \tag{8}$$

where p_j is a probability of kill given engagement. This is an equation of Lanchester-square form (cf. process L3 of [3] with engaged attackers allocated proportionally among different types of interceptors. The assumptions implicit in (8) disallow representation of differing engagement capabilities of different types of interceptors. Note also the assumption that attackers, if sufficiently numerous, can engage all interceptors, and conversely. We also remark that (8), and equation (9) below are obtained by replacing the random numbers of interceptors penetrating the escort screen by their expectations. No explanation is given as to why a square law equation is appropriate here, whereas linear law was appropriate for the interceptor-escort interaction.

The number of attackers killed by interceptors is then computed using the equation

$$\Delta A = A \frac{\sum_j q_j I_j^{(1)}}{\sum_\ell I_\ell^{(1)}} \tag{9}$$

where the q_j are conditional probabilities of kill given engagement. This equation also is of Lanchester-square form.

3. Ground-to-Air

Attrition of aircraft caused by ground situated air defense sites is calculated by means of a multiple shot binomial attrition equation. There are two types of air defenses, long range and short range; within a given sector there are M_1 long range sites uniformly distributed over the sector, M_{21} short range sites distributed over a forward area near the FEBA and M_{22} short range sites distributed over the rear portion of the sector. The latter differentiation allows for differential effectiveness of short range sites. The number of attacking aircraft killed is then computed as

$$\Delta A = A[1-(1-p_1)^{M_1}(1-p_{21})^{M_{21}}(1-p_{22})^{M_{22}}] , \tag{10}$$

where

A = number of attacking aircraft ,

and p_1, p_{21}, p_{22} are probabilities of kill. Thus different sites act independently, and any aircraft is equally likely to be killed by any site of a given type. Moreover, attacks by different sites on a given aircraft are independent, in the sense that whether the aircraft escapes one site is independent of whether any other sites are evaded. The "constant degree of saturation" claimed in the report is in fact zero, since (10) is based on the assumption that every site can attack every penetrating aircraft. This assumption is questionable, to say the least. Perhaps a more realistic alternative would be a single-shot binomial equation of the type discussed in [4].

Escorts of attacking aircraft are treated entirely analogously; we therefore omit a detailed description.

Attacking aircraft are also vulnerable to target area defenses. If the aircraft are not on the air defense suppression mission (which is treated differently, as we discuss below) the number of aircraft killed by target area defenses is computed by the equation

$$\Delta A^{(1)} = A^{(1)}[1-(1-r_1)^{s_1}(1-r_2)^{s_2}] , \tag{11}$$

where

$A^{(1)}$ = number of attacking aircraft (those which have survived air defense sites),

s_i = number of type i target defense sites,

r_i = probability an attacking aircraft is killed by a particular site of type i.

The same comments apply to (11) as to (10).

For aircraft whose mission is suppression of long range air defense sites attrition is computed using the equation

$$\Delta B = (1-(1-r)^{s})a(B) + \beta(1-r)^{s} , \tag{12}$$

where

B = number of aircraft attacking site,

s = number of short range sites defending the long range site,

r = probability an attacking aircraft is killed by a particular short range site,

a(B) = number of attack aircraft killed when B aircraft attack the long range site.

The function a is a tabular input to the model.

There seems to be no sensible interpretation to Equation (12). The physical situation seems to be that an attacking

aircraft is vulnerable first to the short range defenses associated with the site and then to the site itself. If this is the case then attrition would be given by

$$\Delta B = a([1-r]^S B) + (1-(1-r)^S)B \quad . \tag{13}$$

That is,

$$B' = (1-(1-r)^S)B$$

of the attackers are killed by short range defenses leaving, $B'' = (1-r)^S B$ attackers to engage the site itself, of which $a(B'')$ are killed by the site.

Outbound attrition to aircraft which have survived target defenses is calculated using Equation (10) as described above. For aircraft on CAS missions, air-to-ground damage is assessed before aircraft attrition.

4. Air-to-Ground

The probability that a given air defense site is destroyed by aircraft on the air defense suppression mission which attack that site is

$$p = p(B) \quad , \tag{14}$$

where

B = number of aircraft attacking that site

and p is a user-defined function giving the probability a site is killed as a function of the number of aircraft attacking it. The number of sites destroyed is thus

$$\Delta S = \sum p(B_i) \tag{15}$$

where B_i is the number of aircraft attacking site i. In addition, each attack on a site leads to the destruction of

$$\Delta t_k = q_k B \tag{16}$$

subsidiary targets of type k, where

q_k = number of type k targets destroyed by one attacking aircraft.

With the exceptions noted below, all other aircraft attrition to ground targets is computed using equations of the form (16). We feel there is little justification for such equations and that sensible and practical alternatives are available (e.g., single shot binomial).

Damage by shallow CAS sorties to weapons of a given type in maneuver units is computed using a mixed mode Lanchester equation of the following form

$$\Delta W = cS + W(1-(1-c')^S) , \tag{17}$$

where

W = number of weapons

S = number of sorties,

c = number of weapons killed by impact-lethality weapons per sortie,

c′ = fraction of weapons destroyed by area fire weapons per sortie.

The parameters c and c′ depend on the type of weapon system and the type of attacking aircraft. These calculations are performed separately for each type of weapon, and can therefore lead to overestimates of attrition unless the c, c′ account for this. We note that (1) and (17) are consistent with one another.

The model computes numbers of sheltered and unsheltered aircraft on the ground and vulnerable to attack under a number of rather reasonable assumptions (e.g., shelters are used as much as possible, all shelters are indistinguishable and equally vulnerable, ···) as well as some questionable assumptions

(unsheltered aircraft are in a distinctly separate area from sheltered aircraft, live targets can be distinguished from dead targets).

The potential number of unsheltered aircraft killed is computed by means of the equation

$$U^{(0)} = \sum_i [a_i M_i + U(1-(1-f_i)^{M_i})], \tag{18}$$

where

M_i = number of attacking aircraft of type i,

a = number of unsheltered aircraft destroyed by one attacking aircraft, using direct fire weapons,

f = fraction of unsheltered aircraft destroyed by one attacking aircraft, using area fire weapons.

This potential total is then adjusted to prevent overkill; that such an adjustment is necessary is an admission that the equation is incorrect in at least some cases. Again, this equation is mixed mode Lanchester in form.

Computations for the attrition of sheltered aircraft and shelters themselves are entirely analogous. If a shelter is destroyed, its contents necessarily are, but not conversely. The attrition computed by (18) is allocated proportionately among types of target aircraft.

A helicopter effects model is included but is entirely in the form of a tabular input.

III. GENERAL COMMENTS

The following are some general comments concerning attrition methodology in Vector-1:

(1) The overall methodology is neither essentially new nor essentially different from some other existing combat models, such as IDAGAM I. Moreover, the mixed mode heterogeneous Lanchester process is recommended in [6] for use in modeling attrition in ground combat. Vector-1 does have range- and movement-dependent attrition rates with the rate used for a given calculation chosen on the basis of the evolution of the simulation. Whether--given the context and level of resolution of the model--this represents an important contribution is uncertain. The detailed assumptions under which attrition rates are computed from physical data concerning weapons and certain interaction data must be regarded as just that: assumptions used to compute inputs to the main model, and not as assumptions from which the model itself is derived. There exists a possibility of inconsistency between the two sets of assumptions. The "micro" set of assumptions used to compute attrition rates evidently specifies (along with certain independence assumptions) the stochastic structure of some attrition process which may not be the same as (1).

(2) The level of detail in attrition computations is not consistent throughout the model. In particular, equations (4) and (16) represent much grosser approximations than do most of the other equations. Whether this has any significant effect on results obtained using Vector-1 is not clear. Ground interactions, in general, appear to have been modeled more carefully and in greater detail than other (especially air-to-air) interactions.

(3) As is true with any iterative deterministic simulation, random variables in Vector-1 are replaced by their expectations (or approximations thereof) for inputs to succeeding calculations. Based on

experiences with Monte Carlo simulations of homogeneous stochastic Lanchester attrition processes [7] we feel that the error so introduced is no greater than that introduced by the other assumptions, such as those underlying (1). It should be noted, however, that the attrition coefficients calculated from primitive data are themselves expectations, which is further grounds for doubting the usefulness of such detailed inputs.

(4) The Lanchester-attrition equation (1) is used in Vector-1 to model an assault on a hasty defense, which is the principal, but not the only, ground interaction in the model (among the others are advances and crossings of urban areas and rivers). All the other interactions are modeled by user-input tables. The only justification for this is an argument that the attrition involved is so small that such procedures are acceptable. This assertion is questionable, particularly for protracted, unintense conflicts.

To conclude, Vector-1 contains two possible contributions to modeling attrition of ground forces: Lanchester attrition coefficients dependent on range and other internal factors and a procedure for computing these attrition coefficients from more primitive data (which must be given in range-dependent, movement-dependent, ... form). Whether either contribution is significant is, we believe, doubtful, in view of the level and number of assumptions necessarily required to obtain a tractable model and in view of the relative lack of attention given to modeling other attrition interactions. In particular, we feel that the model is quite incapable of resolving effects of even substantial variations in its "primitive" inputs.

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MODELING AND SIMULATION IN NET ASSESSMENT

P. A. Karber
Director, Project 186

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FUNCTION OF NET ASSESSMENT

COMPARATIVE EVALUATION OF U.S. AND OPPONENT FORCES

- EMPHASIZING EXPLICIT AND EQUALLY APPLICABLE CRITERIA
- FOCUSING ON:

LONG TERM TRENDS

and

FORCE EFFICIENCY IN LONG TERM PEACETIME COMPETITION

as well as

FORCE EFFECTIVENESS IN COMBAT

GENERAL ATTITUDE TOWARD MODELING

- MODELING A HINDRANCE RATHER THAN A HELP TO ASSESSMENT
- PRODUCT DISSATISFACTION, PARTICULARLY IN TACTICAL GROUND COMBAT SIMULATION
- NET ASSESSMENT INTEGRATION IS NOT LIKELY TO GO TO MODELERS

MOST FREQUENT COMPIAINTS

- ASSUMED TO PROXIMATE REALITY
- LACK OF HISTORICAL/PREDICTIVE VALIDATION
- LEAVE OUT MAJOR QUALITATIVE FACTORS
- EXPLICIT ASSUMPTIONS QUESTIONABLE - FEBA
- MANY HIDDEN ASSUMPTIONS
- OPTIMIZATION OF CAPABILITIES
- ABSTRACTED FROM BLUE EXPERIENCE - RED MIRROR IMAGED
- LITTLE COMPREHENSION OF COMBINED ARMS PROCESS
- SINGLE SOLUTION
- LITTLE DISTINCTION OF LEVELS OF COMBAT

NEED - S. C. P. A.

SIMULATION CONSUMER PROTECTION AGENCY

MODELERS ARE THEIR OWN WORST ENEMY

FALSE ADVERTISING	-	PROMISE MORE THAN THEY CAN DELIVER
FALSE LABELING	-	HIDDEN ASSUMPTIONS - DO NOT SHOW HOW CONCLUSIONS ARE REACHED
POOR QUALITY CONTROL	-	LITTLE SELF POLICING
PHONY COMPETITION	-	CRITIQUES FOCUSED ON METHODOLOGY NOT PRODUCT
	-	NEED MODEL FLYOFF
PRICE INFLATION	-	CONSUMER SUBSIDIZED PRODUCT DEVELOPMENT TOO MANY MODELS TOO MUCH MONEY NOT ENOUGH TO SHOW FOR IT

MODELING CAN NOT BE A SUBSTITUTE FOR:

- CLEAR LOGICAL ANALYSIS
  - DRIVEN BY UNDERSTANDING OF THE PROBLEM RATHER THAN METHODOLOGY
  - HIGHLIGHT IMPLICIT ASSUMPTIONS NOT COVER THEM UP
  - VISUALIZE THE PROCESS OF GETTING FROM PROBLEM TO CONCLUSION
- DECISION-MAKING
  - CANNOT DELEGATE AUTHORITY
  - DECISIONS BASED ON SIMULATION FINDINGS ARE MADE BY THE MODELERS
  - MUST BE ABLE TO CHOOSE BETWEEN OPTIONS
  - PROBLEM OF SINGLE SOLUTION
    - DELEGATE AUTHORITY TO MODELER
    - CHALLENGE/CRITIQUE MODEL
    - DECIDE ON PERSONAL CRITERIA

HIGH CONSUMER INTEREST IN APPROACHES WHICH PROVIDE

- HEURISTIC INSIGHT INTO
  - WHAT GOES ON IN COMBAT
  - UNIQUE CONTINGENCIES
- MEASUREMENT OF QUALITATIVE IMPACT
  - HUMAN FACTORS, SURPRISE, FOG OF WAR, EMPLOYMENT
- CLEAR PRESENTATION OF LOGIC
  - INTERACTION OF VARIABLES
  - TIME SEQUENCING OF EVENTS
- REAL SENSITIVITY ANALYSIS
  - EMPHASIZING RANGE OF OUTCOME RATHER THAN SINGLE SOLUTION
- HIGHLIGHT FORCE ASYMMETRIES

AREAS WITH POTENTIAL HIGH PAY-OFF

- MODEL LOW LEVEL/HIGH RESOLUTION OTEA/INSTRUMENTED EXERCISES
  - STRESSES
    - FORCE INTERACTION
    - QUALITATIVE FACTORS
    - EMPLOYMENT CONCEPTS
  - EDUCATE MODELERS
  - MODELING PERMITS GREATER UTILIZATION OF DATA
    - CHANGE SELECTED INPUTS
    - EMPIRICAL INPUT TO HIGHER LEVEL MODELS
- MULTI LEVEL MODEL INTEGRATION EMPHASIZING VARIABLE IMPACT OF
  - FIREPOWER/WEI/FORCE RATIO
  - MOVEMENT/FORCE TO SPACE RATIO
  - EMPLOYMENT/SUPPORT/C^3
- EMPHASIZE MAN/MACHINE INTERFACE IN HIGH LEVEL/LOW RESOLUTION MODELS
  - GENERALSHIP/ENTROPY VS. FIXED FEBA/RATE FIREPOWER
  - IDENTIFY KEY CHOICE POINTS
  - DECISION-MAKER PARTICIPATION

TITLE: LULEJIAN-I

PROPONENT: WSEG

DEVELOPER: Lulejian & Associates, INc.

PURPOSE: LULEJIAN-I is a computerized analytical, general, non-nuclear warfare model developed for use in making relative assessments of forces, performing force deployment studies and generating information for use in tradeoffs among weapins systems. The outcome opf force interactions is determined in terms of FEBA movement and the attritions of weapons systems and personnel.

GENERAL DESCRIPTION: The LULEJIAN-I model is a rwo-sided deterministic simulation of integrated land and air combat. Ground force interactions are aggregated at the sector (corps) level, but individual battalions are accounted for. It is a theatre level model, but may be applied without modification to corps-level engagements. To determine attrition and movement of the FEBA, the model uses individual weapons performance potentials and a concept of trading space for survivability; it does not use aggregated measures of effectiveness such asfirepower scores. A significant feature of the model is itsuse of game-theoretic techniques to determine approximatelyoptimal allocations of some of the major resources in the theater. The optimization may be two-sided or one-sided,or the allocations may be fixed by the user. Six national poarticipants may be played for each side, with three typesof maneuver battalions per participant. Thirteen weapons typesmay be represented within each battalion. The model also represents for each side five types of tactical aircraft,which can be assigned to any of six mission areas;six types of artillery; two types of attack helicopters; and two typesof ADA weapons.

INPUT: Initial land force and logistics inventory data, and a schedule of weapon, personnel and supply arrivals.

Geographic and terrain data
Logistics systems capabilities and supply consumption data
Weapons performance data

OUTPUT: Tape of the values of all iportant variables used or generated by the model. Report generator manipulates the information on the tape to provide printed results desired by the user. A wide varietv of data can be obtained in available tables whichmay be selected for printing.

MODEL LIMITATIONS: The model is limited to specific maximum numbers of unit ypes, weapon system types and geographic sectors. Memory size and running time of the computers expected to be used were considered in establishingthe limitations.

HARDWARE REQUIREMENTS: The model has been successfully exercised on CDC6400, CDC6500, CDC6600 and Honeywell Multics computers. The minimum storage requirement is approximately 50K (decimal). Peripheral equipment requirements include disc packs and tape.

SOFTWARE:

Programming Language: FORTRAN
DOCUMENTATION: WSEG Report 259, "The LULEJIAN-I Theater Level Model,"which constitutes user's and technical dociumentation.

TIME REQUIREMENTS: Acquire base data and structure it in model format-4 man months. This time can be reduced considerably for other than the initial utilization of the model since much of the data will not change for subsequent studies. Also a data preprocessor is being developed to provide an interface with the OSD data files described in NATO Task Force Memorandum (NTFAM-3). The model requires approximately 1.5 seconds CPU time per combat day, if allocations are fixed. Running times can increase substantially when approximately optimum allocations are being generated.

SECURITY CLASSIFICATION; Unclassified

FREQUENCY OF USE: Newly developed

USERS: Anticipated users include SAGA, OASD(PA&E) and WSEG.

POINT OF CONTACT: Weapons Systems Evaluation Group
400 Army-Navy Drive
Arlington, Virginia, 22202

KEYWORD LISTING: Analytical Model, General War, Land Forces, Air Forces, Computerized, Two-sided, Deterministic, Time Step.

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I. INTRODUCTION

(U) This report describes a theater-level tactical combat model, called Lulejian-I, developed in support of the Director, Weapons Systems Evaluation Group. The Lulejian-I model is a production version of a previously developed prototype model. As such, it incorporates significantly more detail than the prototype as well as some improvements in general approach.

(U) Lulejian-I was built for the purpose of providing a tool to aid in the assessment of alternative force levels, compositions, and deployments in Central Europe. Lulejian-I is unique in its treatment of many aspects of tactical conflict. Its most important characteristic is its ability to determine nearly optimal (enforceable) policies for the allocation of major theater resources. It may also be used, however, to provide substantial illumination of theater outcomes under assumed policies for one or both combatants.

(U) The Lulejian-I model described in this and succeeding volumes is a set of submodels combined in an overall framework that can reasonably simulate many aspects of a tactical conventional war in Europe. The model simulates air operations, ground operations, and logistics operations. Two air regions, five aircraft types per side, and the major tactical air missions are included. Up to ten combat sectors and six national participants per side may be treated. Delays arising in the logistics flow due to opposing air strikes or overloading of available logistics capacity are realistically modeled. The movement of combat units to active on-line status and back to theater reserve is modeled as a function of their combat history. Alternative replacement policies are also treated. The interactions of opposing ground forces include the functional interdependence of maneuver and support units (including tactical aircraft), as well as explicit treatment of weapon system/target interactions. The ground combat assessment methodology assumes that both sides have threshold attrition rates which when exceeded cause them to yield ground in order to manage their losses.

(U) In addition to simulating tactical war in Europe, Lulejian-I includes an automated search process that may be used to identify near-optimal allocation policies for friendly and/or enemy resources over time. In this way the model can minimize the need for the user to make tactical decisions, which might or might not be good decisions, when comparing alternative force postures. The essential feature of this process is that "enforceable bound" outcomes may be obtained for either side. That is, the search process identifies optimal policies that a particular side may use to guarantee that the outcome will be no worse than some bound, even if the opposing side knows each decision the enforcing side will make immediately prior to its being made (and responds optimally). Of course, the enforcing side could do better than the enforceable bound if his opponent does not have prior information or for some other reason does not play optimally.

(U) An "enforceable solution" approach is desirable in that it permits an unbiased comparison of the capabilities of opposing forces. The problem in the past in implementing this approach has been the inability to obtain solutions to situations that involve several types of resources, a large number of decisions concerning the allocation of these resources, and interactions that are non-linear. Lulejian & Associates has derived a generalized solution technique for this problem. It is an iterative, approximate technique for handling multi-move situations which has been successfully applied to the resource allocation problem in the Lulejian-I model.

(U) This volume presents a discussion of the chosen approach to the problem, a brief description of the engagement models and allocation algorithm, and some results of testing the model. Volume II presents a comprehensive description of the logic and equations of the model; Volume III documents the computer implementation of the model.

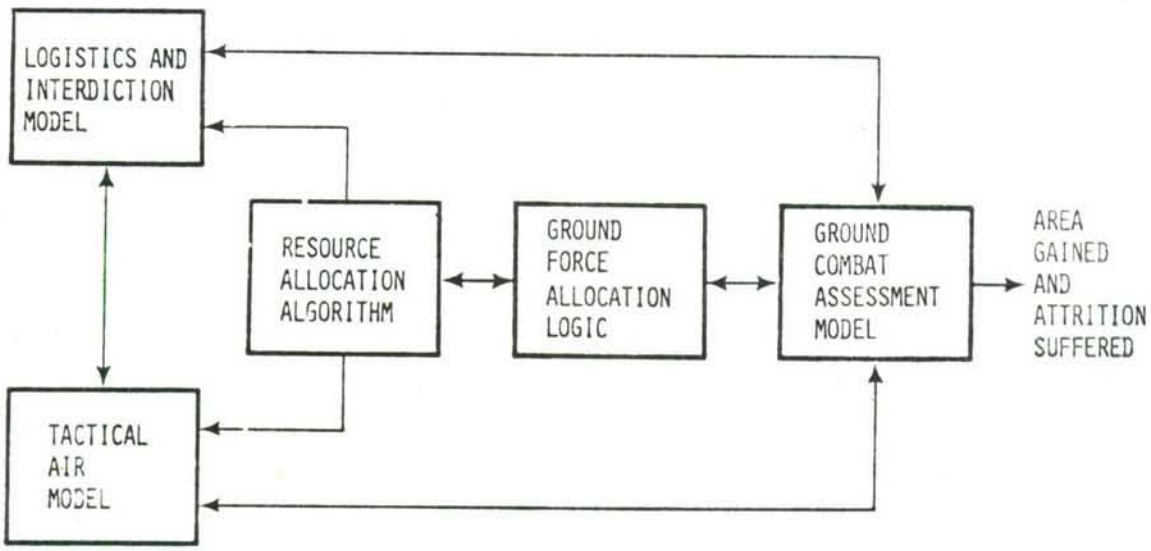
II. APPROACH

(U) The Lulejian-I model is intended for use in assessing alternative European theater force levels, compositions, and deployments. The approach has been to combine relatively simple methodologies for replicating important trends which result from force-on-force interactions with a technique for determining "good" allocation policies for major resources. The combination of individual methodologies yields a model sensitive to variations in force levels and compositions; the use of "good" allocation policies insures that each alternative composition may be evaluated under assumptions of equally "intelligent" use. In addition, a framework is used which provides details of the European theater geographic and political features. This enables the model to be used in examining shifts in the commitment or preparedness of up to six national participants on each side as well as restrictions on the deployment of certain forces (nations) in certain sectors.

(U) Exhibit 1 depicts the organization of the Lulejian-I model's major elements. The three models containing the force-on-force interaction equations are the Logistics and Interdiction Model, the Tactical Air Model, and the Ground Combat Assessment Model. In addition, the Ground Force Allocation Logic has been developed to implement various replacement policies the user may select. This logic is also responsible for the allocation of units in theater reserve to the combat sectors where they are needed and for the movement of on-line units to reserve when their past casualty history so dictates. The Resource Allocation Algorithm controls the search for "good" allocation policies.

(U) It is important to note that there are many "allocation decisions" which must be simulated by any tactical combat model. Lulejian-I is perhaps unique in its ability to ensure "good" choices for most major decisions. However, it would be impractical from a computation standpoint to apply

EXHIBIT 1 (U)
MAJOR MODEL ELEMENTS



the Resource Allocation Algorithm to all allocation decisions. Consequently, there are some decisions which must be made by the user through his inputs, and there are some decisions which are made according to built-in rules (the rules logically depend on events which may or may not happen during the campaign). Exhibit 2 is a summary of the major allocation decisions made by Lulejian-I.

(U) The conceptual theater setup of Lulejian-I is depicted in Exhibit 3. There may be as many as ten combat sectors. Each sector may have up to 15 segments which are distinguished individually by their depth, width, and terrain. There are two air defense regions for each side, each of which contains air base and supply stockage systems. Resources that arrive at the theater enter through a conceptual base of operations. A logistics system (not shown in Exhibit 3) is responsible for supporting the flow of supplies from stockpiles in the base of operations to stockpiles in forward areas.

EXHIBIT 2 (U)

SUMMARY OF MAJOR ALLOCATION DECISIONS

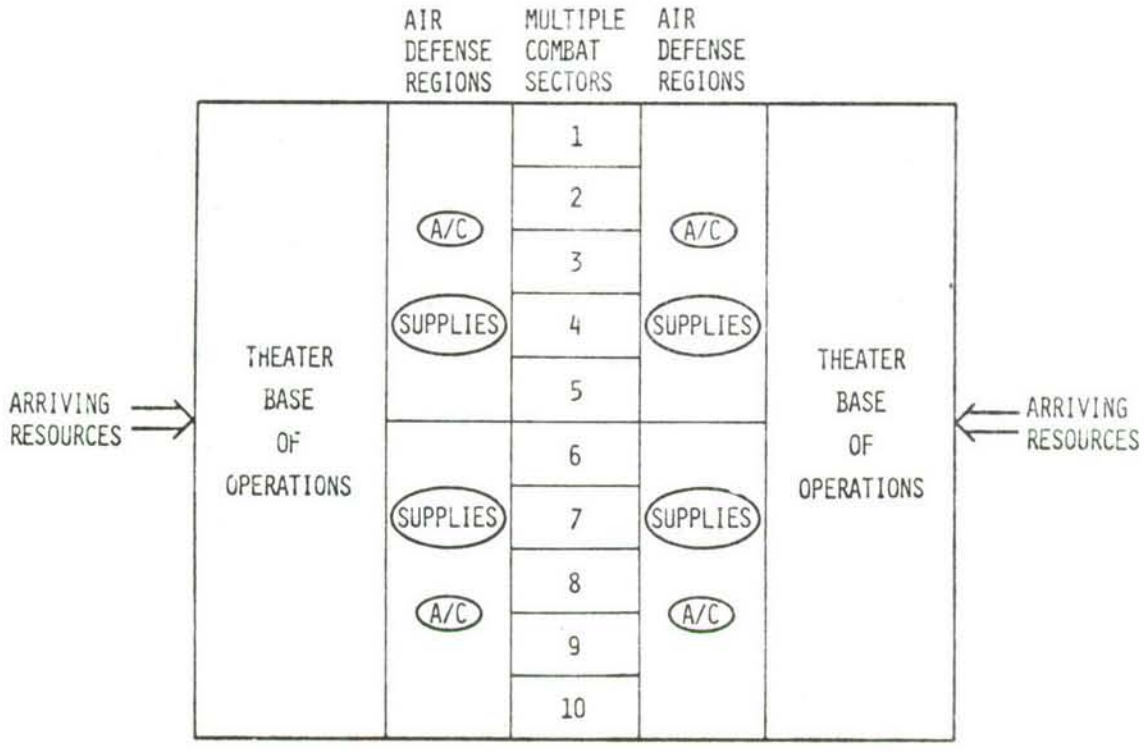
RESOURCE	ALLOCATION DECISIONS WHICH MAY BE "OPTIMIZED"	ALLOCATION DECISIONS MADE BY USER INPUT	ALLOCATION DECISIONS MADE BY "BUILT IN" RULES
Tonnage delivered into the theater base of operations	Relative proportions of: Consumable supplies Transport vehicles Supplies to build in-theater transport capacity	Scheduled deployments of: Combat units Equipment replacements Personnel replacements	Allocation of supplies to users based on demand
Tactical air forces	Relative emphasis on air mission areas: Air defense Air base attack Combat air support Interdiction ADA suppression Escort	Which aircraft types are capable of performing which missions Fraction of combat air support aircraft which attack: Armor Personnel Support weapons	Relative proportions of air defense assigned to: Interdiction targets Combat areas Relative proportions of combat air support in: Sector 1 Sector 2 etc.
Ground Combat Forces	Extent of initial massing of the attacking side's forces Number of sectors in which attacking side attacks initially	"Unit," "individual" or "modified" replacement policy Extent to which "success" is reinforced with reserves as opposed to "failure"	When to remove on-line battalions When to change posture (attack, hold, delay) in a particular sector

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EXHIBIT 3 (U)

CONCEPTUAL THEATER ORGANIZATION



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III. ELEMENTS OF THE MODEL

(U) The basic elements of the Lulejian-I model are illustrated in Exhibit 1. The model includes five submodels: a Logistics and Interdiction Model, a Tactical Air Model, a Ground Combat Assessment Model, Ground Force Allocation Logic, and a Resource Allocation Algorithm. A brief functional description of these submodels is presented below. In some cases numerical examples are given to illustrate their behavior. Volume II of this report presents a comprehensive analytical description (i.e., the logic and equations) of the models.

A. LOGISTICS AND INTERDICTION MODEL

(U) For the Lulejian-I model this element is a relatively simple, highly aggregated model of logistics flow in a theater. It includes, for example, a single "pipeline" to simulate the movement of logistics through a network toward the front in lieu of a detailed set of arcs and nodes commonly used in theater-level models to describe the logistics network.

(U) Exhibit 4 summarizes the elements, functions, and interactions of the Logistics and Interdiction Model. Up to 45 different types of resources may enter the theater as specified by user input. Some of these are stockpiled temporarily in the theater base of operations area until they can be airlifted or otherwise transported to the forward combat areas. In Lulejian-I it has been assumed that supply stockages at the theater base of operations are not vulnerable to attack by opposing forces.

(U) Combat units entering the theater port reach the front through the ground logistics network and are assumed to be transported by their own (organic) vehicles. Individual infantry replacements and general supplies (ammunition, food, etc.) are moved either by airlift or through the ground logistics network by logistics vehicles. The assumed priority is replacements and then supplies to airlift; replacements and supplies that are not airlifted move through the ground logistics network as empty logistics vehicles are available at port. Flow through the network is a function of vehicles

EXHIBIT 4 (U)

LOGISTICS AND INTERDICTION MODEL INTERACTIONS

ELEMENTS	FUNCTIONS	INTERACT WITH:
SUPPLY STOCKAGE AT THEATER BASE OF OPERATIONS	RECEIVES ARRIVING THEATER RESOURCES	AIRLIFT A/C, EMPTY NETWORK VEHICLES
AIRLIFT A/C, LOGISTICS VEHICLES	PROVIDE CAPABILITY TO TRANSPORT SUPPLIES	SUPPLY STOCKAGES AT BASE OF OPERATIONS, OPPOSING TACTICAL A/C, LOGISTICS NETWORK, REGIONAL SUPPLY DEPOTS
LOGISTICS NETWORK CAPACITY	SUPPORTS MOVEMENT OF VEHICLES FROM BASE OF OPERATIONS TO REGIONAL DEPOTS	LOGISTICS VEHICLES, ORGANIC COMBAT UNIT VEHICLES, OPPOSING TACTICAL A/C
REGIONAL SUPPLY STOCKAGES	SUPPORT ACTIVITY OF AIR AND GROUND FORCES	LOGISTICS VEHICLES, OPPOSING TACTICAL A/C, FRIENDLY AIR AND GROUND FORCES

available, network capacity, and the length of the network. The network length changes with FEBA movement. Thus, a rapid advance by friendly forces will result in a stretched supply line and a reduced output delivered to the front, for a given input and number of transport vehicles available.

(U) Engineering supplies are a resource allocation that permits the capacity of the network to be increased. In cases where air interdiction is effective in reducing capacity or where capacity is insufficient to support front line units and move replacements, increasing capacity may be optimal. Since the total theater input tonnage is assumed fixed, any allocations to engineering supplies decreases the ability to bring in other inputs (e.g., empty vehicles and general supplies).

(U) In addition to interdiction of network capacity, the logistics system is vulnerable to direct attacks on vehicles. Attrition of combat units, individual replacements, and supplies in the network on any given day is assessed

in proportion to the relative number of vehicles loaded with each type of resource in the network on that day. As in the case of engineering supplies, additional vehicles are a resource allocation that is used to increase the network flow at the expense of other possible theater inputs. Network defense is by SAM units deployed in both an area deployment mode and a point defense mode (e.g., defense of network bridges).

(U) Combat units exit the network and are transferred to theater reserve status. The Ground Force Allocation Logic handles the allocation of these units to each sector of the front. Individual replacements are transferred in a similar manner. Supplies exit the network and are allocated to regional supply depots based on demand. Supply depots are vulnerable to possible interdiction by opposing tactical air. SAM units are allocated directly to point targets (depots, bridges, and air bases) and to area and barrier deployments (network defense and FEBA defenses). Replacement missiles are allocated to SAM depots and allocated out of depot based on demand (use and attrition of point and area SAMs).

(U) The Logistics and Interdiction Model was constructed with the idea of including the major characteristics of flow of resources from a theater depot to the front and the interactions among flow rates, FEBA movement, air interdiction, and SAM defense in as simple a manner as possible. Exhibits 5 and 6 graphically illustrate the working characteristics of the Logistics and Interdiction Model.

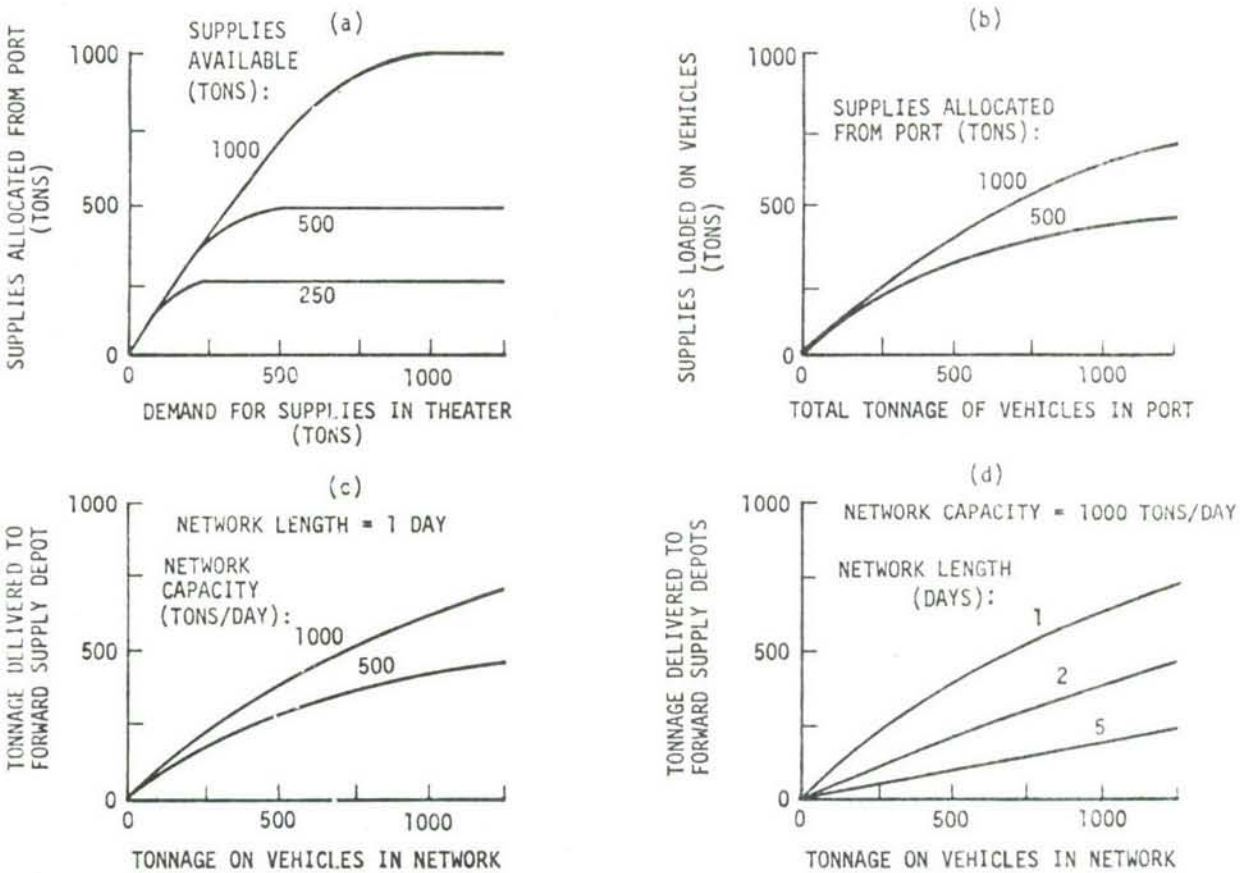
(U) Exhibit 5 illustrates how supply levels, vehicle availability, network capacity, and network length act together to determine the flow of supplies through the logistics network.

(U) The equations of the Logistics and Interdiction Model were used to compute the relationships illustrated. In Exhibit 5a the tonnage of supplies allocated from port is shown as a function of theater demand for various levels of supply availability. The pertinent model equation is:

$$S_A = S_D \left\{ 1 + .5 \left[1 - \exp \left(- \frac{S_P - S_D}{.5 S_D} \right) \right] \right\} \qquad (1)$$

EXHIBIT 5 (U)

NATURE OF LOGISTICS AND INTERDICTION MODEL



where

S_P = supplies available in port (tons)

S_D = supply demand in theater (tons)

S_A = supplies allocated from port (tons).

(U) In Exhibit 5b the tonnage of supplies loaded on vehicles is shown as a function of vehicle availability in port (total tonnage) for various levels of tonnage allocated to be loaded. The pertinent model equation is

$$S_L = V_P \cdot T_V \left\{ 1 - \exp \left[- \frac{S_A}{V_P \cdot T_V} \right] \right\} \qquad (2)$$

where

S_A = supplies allocated (tons)

V_P = vehicles in port

T_V = tons carried per vehicle

S_L = supplies loaded (tons).

(U) In Exhibits 5c and 5d the tonnage of supplies delivered out of the network to forward depots is shown as a function of the tonnage on vehicles in the network for various network capacities and network lengths. The pertinent model equation is

$$S_O = T_V \cdot C_N \left\{ 1 - \exp \left[- \frac{V_N \cdot T_V}{\tau \cdot T_V \cdot C_N} \right] \right\} \qquad (3)$$

where

V_N = total vehicles in the network

T_V = tonnage carried per vehicle

C_N = network capacity (vehicles/day)

τ = network length (days)

S_O = supplies delivered out of network (tons).

The total number of vehicles in the network is assumed for these two exhibits to consist only of those loaded with supplies.

(U) From Exhibit 5a and Equation (1), it may be seen that supplies are allocated from port in proportion to the theater demand. When supplies available in port are plentiful relative to demand ($S_P >> S_D$), approximately 50 percent more than the quantity demanded is allocated. When supplies available in port are equal to or less than the quantity demanded ($S_P \leq S_D$) the total amount available is allocated.

(U) From Exhibit 5b and Equation (2), it may be seen that a degree of inefficiency is assumed in the ability to load vehicles at the port. When the number of vehicles, or the tonnage thus represented, is small relative to the amount of supplies allocated from port ($V_P \cdot T_V << S_A$), nearly all the available vehicles are loaded. However, if the number of vehicles, or vehicle tonnage, is about equal to the tonnage of supplies allocated, only about 65 percent of the allocated tonnage will be loaded. In the limit, when the vehicle tonnage available is large compared to the supply tonnage allocated, nearly all of the supplies allocated will be loaded.

(U) From Exhibits 5c and 5d and Equation (3), it may be seen that the tonnage delivered out of the network increases with the tonnage in the network, but the proportion of tonnage delivered decreases as either the length of the network (in average travel time) or the load on network capacity (tonnage in the network compared to network capacity) increases.

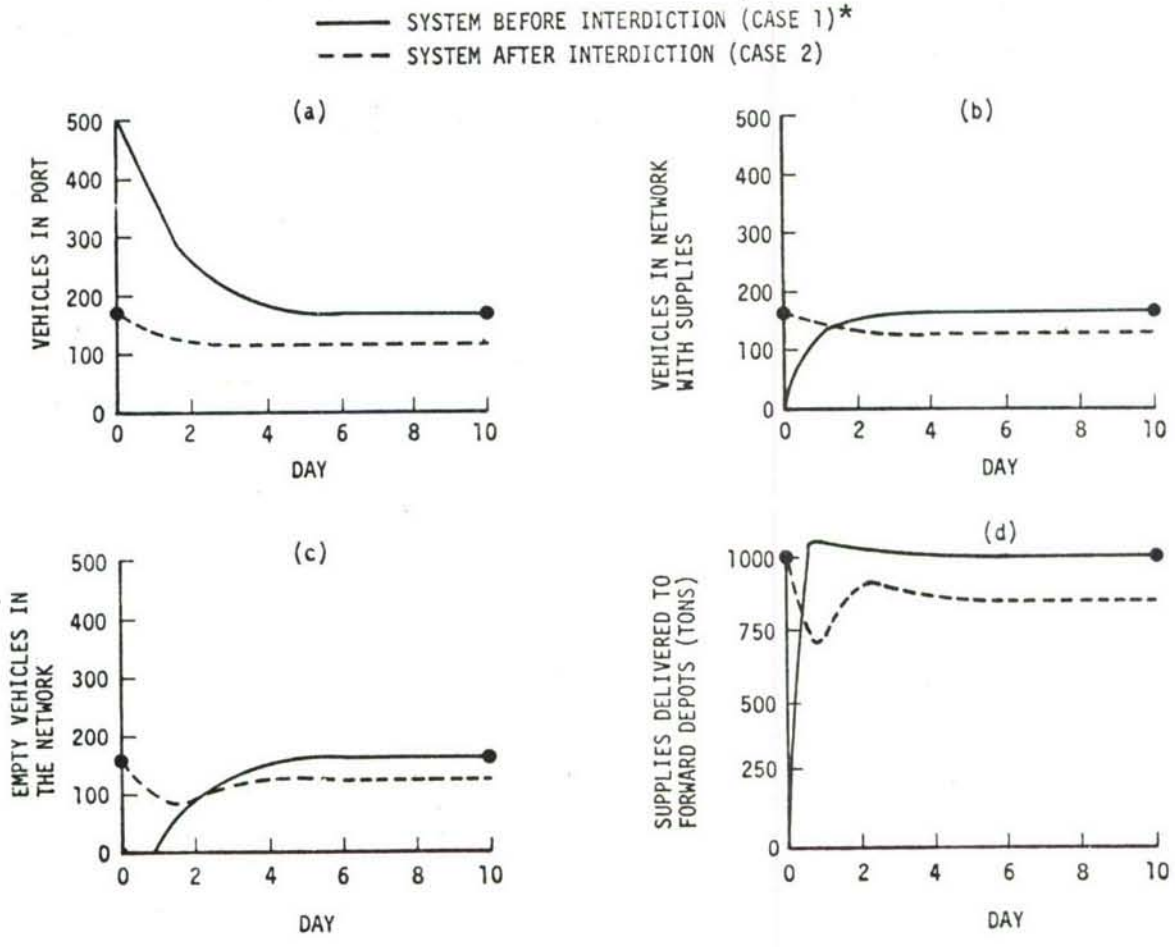
(U) In Exhibits 5c and 5d the presence of empty vehicles in the network was ignored. In Exhibit 6 the effect of empty vehicles traveling back toward port is included in an examination of the transient behavior of the logistics system.

(U) Exhibit 6 illustrates the transient behavior of the logistics system in a start-up situation, and in the case of a steady-state situation when disturbed by interdiction of logistics vehicles.

(U) Model Equations (1) through (3) were used. A constant level of supplies in port of 10,000 tons, a constant daily demand of 1000 tons, a network capacity of 300 vehicles per day, and a network length of one day's travel were assumed.

EXHIBIT 6 (U)

TRANSIENT BEHAVIOR OF LOGISTICS AND INTERDICTION MODEL



*Please note that the end point of the solid curve (•) has been "folded" back to the origin and is also the beginning point of the dashed curve. Interdiction is assumed to occur at day 10 only.

Each vehicle was assumed to carry 10 tons of supply. The transient behavior of the system was examined for the start-up situation in which it was assumed that 500 vehicles were initially in port and no vehicles were in the network (solid curves). Calculations were made assuming enough time for a steady-state condition to be reached. A second case was examined starting with the steady-state conditions of the first case (170 vehicles in port, and 165 full vehicles and 165 empty vehicles in the network) and assuming a one-time loss of 40 percent of the vehicles in the network (132 vehicles killed) due to air interdiction (dashed curves).

(U) As shown by the solid curves of Exhibit 6, in the first case a steady-state condition is reached after approximately four days. The first case was chosen to illustrate the numbers of vehicles required to sustain a network output equal to demand. It can be seen that, for the assumed parameter values, 500 vehicles in the system can support a steady-state flow of 100 loaded supply vehicles arriving at forward depots each day.

(U) It can be seen from the dashed curves of Exhibit 6 that the numbers of vehicles in port and in the network undergo a smooth readjustment after the effects of interdiction are introduced. The most dramatic effect is an approximately 25 percent decrease in supplies delivered to depots immediately following the vehicle interdiction. The long-term effect of the loss of vehicles shows up as a 15 percent decrease in steady-state daily flow of supplies to forward depots.

(U) The reason a loss of 26 percent of the total of vehicles in the system causes only a 15 percent loss in system effectiveness is that the efficiency of the network increases as the load on it is decreased. The loss of vehicles is therefore in part self-compensating.

(U) A similar effect on the flow of supplies to forward depots could be caused by the interdiction of network capacity. Whereas the effect of vehicle interdiction may be relieved by bringing more vehicles into the theater, the remedy for capacity interdiction would be to bring in engineering supplies which would then have to move at least part way through an already overloaded network before they could be used. In this way the loss of network capacity is in part self-compounding.

(U) Although the Logistics and Interdiction Model behavior illustrated in Exhibits 5 and 6 is obtained through somewhat simplified equations, it is felt that it reasonably represents the major functions of a logistics system and the impact of air interdiction on logistics flow.

B. TACTICAL AIR MODEL

(U) The Tactical Air Model consists of logic and engagement equations describing the various missions and allocations of tactical combat aircraft in theater operations. The features of the Tactical Air Model are:

Five aircraft types

Six mission areas

Air-to-air interactions modeled as many-on-many

Penetration of barrier, area, and point SAMs and AAA* explicitly modeled

Both electronic measures and attack against SAM sites modeled

Interdiction of aircraft in shelters and in the open

Attack of both infantry and armor in close combat air support and interdiction of supporting elements in the combat area

Attrition of each type aircraft calculated separately

Sortie rates and effectiveness vary by type and mission area

These features permit the model to be used in assessing the effectiveness of various mixes of aircraft. For example, an aircraft type which had great effectiveness in the combat air support mission but was quite vulnerable to opposing air defense aircraft would benefit from the introduction of fighter aircraft useful in the escort role. Because mission effectiveness varies by aircraft type and mission area, the model user is not constrained to single notional munition loads for each type.

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*SAMs and AAA will sometimes be referred to collectively as "Air Defense Artillery," or "ADA."

(U) Exhibit 7 shows the four primary and two support mission areas and the specific missions included within each. Each allocation policy which may be chosen (there are 18 possible) emphasizes two mission areas. The number of each type of aircraft allocated to each mission area is dependent upon the two mission areas emphasized and the ability of the various aircraft types to perform the missions. A "ranking matrix," Exhibit 8, provides the basis for determining which aircraft types may perform which missions. This is a user input. An entry of zero means that type cannot perform that mission. An entry of three means that type may routinely be used in that mission area. An entry of two means that type should be given some preference in being assigned to that mission area when that mission is one of the two being emphasized. An entry of unity means that type will be heavily allocated to that mission area when that mission area is emphasized. Note that any combination of zeros, ones, twos, and threes may be used. If all non-zero entries were threes, for instance, no preference would be given to any aircraft type in any mission area. The user should be careful not to introduce any bias which cannot be substantiated through independent analyses.

(U) Exhibit 9 illustrates the actual allocations that result from the ranking matrix of Exhibit 8 when the policy is to emphasize either air base interdiction and escort or combat air support and air defense. The 18 possible pairs of missions that constitute the policy choices are shown in Exhibit 10. Note that ordering is important and that no support mission (suppression or escort) is listed first.

(U) Given an actual allocation of aircraft to mission areas, some further sub-allocation to missions is done. Exhibit 11 shows the sub-allocation choices and the bases upon which these decisions are made. It should be noted that combat air support sorties are allocated only to active sectors and then among those sectors in proportion to the total number of battalions committed to those sectors, including both sides' forces. This total is felt to be a fairly good indication of the intensity of activity in the various sectors.

EXHIBIT 7 (U)

TACTICAL AIRCRAFT MISSIONS

MISSION AREA	MISSIONS
AIR DEFENSE	AIR DEFENSE OF AIR BASES, LOGISTICS TARGETS, AND THE COMBAT AREA
AIR INTERDICTION OF AIR BASES	ATTACK OF AIR BASES
AIR INTERDICTION OF LOGISTICS TARGETS	ATTACK BRIDGES, VEHICLES ON THE LINES OF COMMUNICATION, AND STORAGE DEPOTS
COMBAT AIR SUPPORT	PROVIDE CLOSE COMBAT AIR SUPPORT AND INTERDICT TARGETS IN THE COMBAT AREA
SUPPRESSION OF AIR DEFENSE ARTILLERY	SUPPRESS AND ATTACK OF AIR DEFENSE ARTILLERY ENCOUNTERED BY PRIMARY MISSION AIRCRAFT
ESCORT	ATTACK ENEMY AIR DEFENSE AIRCRAFT THAT ATTEMPT TO ENGAGE PRIMARY MISSION AIRCRAFT AND THEIR SUPPORT AIRCRAFT

EXHIBIT 8 (U)

EXAMPLE TACTICAL AIRCRAFT RANKING MATRIX

(RELATIVE RANKING OF TYPE IN MISSION AREA)

MISSION AREA:

TYPE	AIR DEF.	AIR BASE INTERDICTION	LOGISTICS INTERDICTION	COMBAT AIR SUPPORT	SUPPRESSION OF ADA	ESCORT
FIGHTER-INTERCEPTOR	1	0	2	3	2	2
MULTI-PURPOSE A/C	2	3	3	3	3	2
ATTACK A/C	0	3	1	2	3	0
COMBAT AIR SUPPORT A/C	0	0	3	1	3	0
TACTICAL BOMBER	0	1	2	0	2	0

EXHIBIT 9 (U)

EXAMPLE AIRCRAFT ALLOCATION CHOICES

EMPHASIS: AIR BASE INT. - ESCORT

TYPE	MISSION DEF	AB	LOG	CAS	SUP	ESC
F-I (800)	84	0	84	84	84	464
MULTI-PUR. (700)	68	256	68	68	68	172
ATTK. (200)	0	85	39	39	39	0
CAS. (600)	0	0	200	200	200	0
TAC. BOMBER (300)	0	242	29	0	29	0

EMPHASIS: COMBAT AIR SUPPORT - DEFENSE

MISSION DEF	AB	LOG	CAS	SUP	ESC
205	0	96	307	96	96
172	68	68	256	68	68
0	27	27	119	27	0
0	0	58	484	58	0
0	100	100	0	100	0

EXHIBIT 10 (U)

TACTICAL AIRCRAFT ALLOCATION POLICY CHOICES

1. AIR DEFENSE - AIR BASE INTERDICTION
2. AIR DEFENSE - LOGISTICS INTERDICTION
3. AIR DEFENSE - COMBAT AIR SUPPORT
4. AIR BASE INTERDICTION - AIR DEFENSE
5. AIR BASE INTERDICTION - LOGISTICS INTERDICTION
6. AIR BASE INTERDICTION - COMBAT AIR SUPPORT
7. AIR BASE INTERDICTION - ADA SUPPRESSION
8. AIR BASE INTERDICTION - ESCORT
9. LOGISTICS INTERDICTION - AIR DEFENSE
10. LOGISTICS INTERDICTION - AIR BASE INTERDICTION
11. LOGISTICS INTERDICTION - COMBAT AIR SUPPORT
12. LOGISTICS INTERDICTION - ADA SUPPRESSION
13. LOGISTICS INTERDICTION - ESCORT
14. COMBAT AIR SUPPORT - AIR DEFENSE
15. COMBAT AIR SUPPORT - AIR BASE INTERDICTION
16. COMBAT AIR SUPPORT - LOGISTICS INTERDICTION
17. COMBAT AIR SUPPORT - ADA SUPPRESSION
18. COMBAT AIR SUPPORT - ESCORT

EXHIBIT 11 (U)

SUB-ALLOCATION OF AIRCRAFT WITHIN MISSION AREAS

MISSION AREA	SUB-ALLOCATION CHOICES	SUB-ALLOCATION BASIS
AIR DEFENSE	• DEFENSE OF AIR BASES AND LOGISTICS NETWORK • DEFENSE OF COMBAT SECTORS	IN PROPORTION TO ENEMY PRIMARY MISSION AIRCRAFT
COMBAT AIR SUPPORT	• VARIOUS SECTORS	IN PROPORTION TO TOTAL BATTALIONS ON LINE
SUPPRESSION OF AIR DEFENSE ARTILLERY ESCORT	• SUPPORT OF AIR BASE ATTACKERS • SUPPORT OF LOGISTICS INTERDICTION AIRCRAFT • SUPPORT OF COMBAT AIR SUPPORT AIRCRAFT	IN PROPORTION TO FRIENDLY PRIMARY MISSION AIRCRAFT

(U) Aircraft allocated to interdiction of logistics targets may be further allocated to attack of network capacity (bridges), vehicles in the network, or forward supply depots. These sub-allocations are determined by a sub-optimization process described fully in Volume II.

(U) Aircraft allocated to close combat air support are further allocated to sectors as noted above. Within each sector sub-allocation among three types of targets occurs. A specific fraction of combat air support aircraft are allocated to suppression of artillery and tanks being used in a support role. The remaining aircraft are split between the attack of troops and armored vehicles in contact with friendly units.

(U) Aircraft allocated to SAM suppression by the Resource Allocation Algorithm are split among FEBA SAMs, area deployed SAMs, and SAMs at point targets in proportion to the numbers of friendly aircraft which must penetrate these defenses.

(U) Aircraft can encounter SAMs on all attack missions: barrier SAMs in attack of the FEBA; area SAMs for all deep strikes (network, depot, vehicle, and air base attack); and both area and point defense SAMs for attacks against air bases, depots, and bridges. Aircraft encounter barrier SAMs in FEBA attack in proportion to the linear density of SAMs across a sector of the front and encounter area SAMs during penetration in proportion to the density of sites and the penetration distance. They encounter all SAMs deployed at air bases. Suppression attacks against barrier, area, or point deployed SAMs are treated as attacks on point targets. There follows some probability of aircraft attrition and some probability the SAM site is destroyed.

(U) Aircraft allocated to FEBA defense patrol the front and attempt to engage opposing aircraft on close combat air support missions. Some fraction of attack aircraft are detected and engaged. Engaged attack aircraft are assumed to abort their weapons and engage in air-to-air combat. Those not engaged continue on to target. Aircraft allocated to defense against deep attack missions (e.g., against air bases and bridges) are assumed to be alerted by GCI and act as a screen against the penetrating force of attack aircraft. As in FEBA defense, some of the penetrators are detected, abort their weapons, and engage in air-to-air combat. Those not engaged continue on to target.

(U) Given penetration of air and ground defenses, attack potential is a function of both the ability to acquire the target and the ability to kill the target once it is acquired. In attacks on air bases, only damage to aircraft is considered (i.e., runway cratering and destruction of facilities are not considered). Aircraft on the ground are assumed to be either in shelters or in the open, depending on the number of shelters available, and damage is assessed based on the proportion of aircraft in these two basing modes.

(U) For attack sorties against the FEBA, the sequence of events modeled is 1) encounters with barrier SAMs (with or without defense suppression); 2) encounters with opposing aircraft in FEBA defense; 3) encounters with AAA; and 4) attack of designated targets (tanks, infantry, or artillery). For attack

sorties against air bases and interdiction targets, the sequence is 1) encounters with area SAMs (with or without defense suppression); 2) encounters with opposing aircraft allocated to air defense; 3) encounters with AAA; 4) encounters with point SAMs (with or without defense suppression); and 5) attack of designated targets (air bases, bridges, vehicles, or depots). Area SAMs that were not suppressed during entry and AAA are also encountered on the return leg.

(U) Exhibit 12 lists the interactions that are simulated by equations of the Tactical Air Model. A detailed discussion of all those equations is given in Volume II of this report.

EXHIBIT 12 (U)

INTERACTION EQUATIONS

- SUPPRESSION OF AREA AIR DEFENSE ARTILLERY (ADA)
- ATTRITION OF AIRCRAFT BY AREA AIR DEFENSE ARTILLERY
- AIR BATTLE: AIR DEFENSE AIRCRAFT ENGAGED BY ESCORT AIRCRAFT
  - AIR BASE AND LOGISTICS INTERDICTION AIRCRAFT ENGAGED BY AIR DEFENSE AIRCRAFT
  - COMBAT AIR SUPPORT AIRCRAFT ENGAGED BY AIR DEFENSE AIRCRAFT
- SUPPRESSION OF ADA AT LOGISTICS TARGETS AND AIR BASES
- ATTRITION OF AIRCRAFT BY ADA AT LOGISTICS TARGETS AND AIR BASES
- SUPPRESSION OF ADA IN COMBAT AREA
- ATTRITION OF AIRCRAFT BY ADA IN COMBAT AREA
- AIR BASE ATTACK

C. GROUND COMBAT ASSESSMENT MODEL

(U) The model used to assess the interaction of opposing ground forces and the effects of combat air support was developed with two fundamental objectives in mind: 1) the model should reflect the individual contributions and interactions of the major combat units of the division (armor, infantry, and artillery) and also reflect the influence of air units on the outcome of ground combat; and 2) suitable simplicity of methodology should be employed so that multi-day theater-level interactions could be efficiently simulated. Modifications to the prototype Lulejian model have resulted in changes in the engagement equations to provide for the inclusion of armored personnel carriers (APCs).

(U) The scope of the Ground Combat Assessment Model of Lulejian-I includes:

Six national participants per side

Three battalion types per participant

Thirteen weapon types per battalion

Six types of artillery per side

Two types of attack helicopters per side

Each type of battalion, for a given participant, may have a different table of organization and equipment (TOE). The 13 weapon types per battalion include three types of APCs, three types of tanks, three types of anti-tank weapons, three types of mortars, and hand-held weapons, with the battalion restrictions as indicated in Exhibit 13.

(U) The primary elements and sub-elements which are treated in the Ground Combat Assessment Model, as well as their functions and vulnerabilities, are displayed in Exhibit 14. The basic logic of the model reflects the assumption that the primary function of infantry and armored maneuver units is to occupy territory and to localize opposing maneuver units (targets) so that firepower may be applied to them.

(U) Firepower is assumed to be of two classes, direct and indirect, and to be provided by two general sources: weapon systems within maneuver units and weapon systems within support units. Direct firepower is provided

EXHIBIT 13 (U)

ORGANIZATION OF BATTALIONS

Battalion Type 1 - "Infantry"

Rifle personnel - those of the particular national participant
Mortars - 1, 2, or 3 types
Anti-tank weapons - 1, 2, or 3 types
APCs - none
Tanks - none

Battalion Type 2 - "Mechanized Infantry"

Rifle personnel - those of the particular national participant
Mortars - 1, 2, or 3 types
Anti-tank weapons - 1, 2, or 3 types
APCs - 1, 2, or 3 types
Tanks - none

Battalion Type 3 - "Tank"

Rifle personnel - none
Mortars - 1, 2, or 3 types
Anti-tank weapons - none
APCs - none
Tanks - 1, 2, or 3 types

EXHIBIT 14 (U)

GROUND COMBAT ASSESSMENT MODEL

ELEMENTS	SUB-ELEMENTS	FUNCTIONS	VULNERABLE TO:
INFANTRY, MECHANIZED INFANTRY, AND ARMOR	INFANTRY BATTALIONS, MECHANIZED INFANTRY BATTALIONS, AND TANK BATTALIONS	CONTACT, LOCALIZE, & ENGAGE OPPOSING MANEUVER UNITS	DIRECT AND INDIRECT FIRE OF OPPOSING: MANEUVER UNITS ARTILLERY UNITS COMBAT AIR SUPPORT UNITS
ARTILLERY BATTALIONS	ARTILLERY TUBES	PROVIDE INDIRECT FIRE IN SUPPORT OF MANEUVER UNITS	COMBAT AIR SUPPORT AND COUNTERFIRE
TACTICAL AIR	TAC AIRCRAFT	PROVIDE DIRECT AND INDIRECT FIRE IN SUPPORT OF MANEUVER UNITS	AAA AND SAMs (AND FEBA DEFENSE AIRCRAFT)
AIR DEFENSE ARTILLERY	SAMs AND AAA	AIR DEFENSE OF THE COMBAT AREA	TACTICAL AIRCRAFT
ATTACK HELICOPTERS	---	PROVIDE DIRECT AND INDIRECT FIRE IN SUPPORT OF MANEUVER UNITS	AAA AND SAMs

by those weapons systems which are employed against a specific element of an opposing maneuver unit, e.g., an infantryman, a tank, or an anti-tank weapon. Indirect firepower is provided by those weapon systems which are employed against an area which may be occupied by opposing maneuver unit elements, e.g., a squad location, a company location, etc. The functional elements of maneuver units in the Lulejian-I model are tanks employing the main tank gun and infantrymen employing rifles, machine guns, mortars, and anti-tank weapons. Support units include tanks used in a support mode, artillery units, attack helicopters, and tactical aircraft allocated to the close combat air support mission.

(U) The outcomes are measured in terms of forces remaining (by type), casualties sustained, and movement of the FEBA. The day's FEBA movement is a function of two factors:

1) The amount of "resolve" possessed by each side to hold or acquire territory, which, itself, reflects two separate facets of combat: a) the number of maneuver units (battalions) that are "committed on line," i.e., committed to the battle by the opposing sides, and b) the threshold loss rate that each of these units is able to sustain and still realize an objective; and,

2) The actual loss rates that are sustained by the maneuver units of each side during the day's combat.

(U) A concept of trading space for survivability is used in the predictive equations for FEBA movement. In effect, the attacker acquires territory if he can inflict losses on the defending force in excess of the level that the defender is willing to accept to hold the position. By increasing the average separation distance between the opposing engaged forces (i.e., yielding territory), the defender manages the attrition so that it does not become excessively large. Both sides are always assumed to have the choice of trading-off between a) the rate at which they are sustaining losses, and b) the amount of territory they control. The equations in the model for predicting attrition of maneuver units reflect this management.

(U) The model's "scenario" begins with each side choosing a deployment strategy; this governs the number of units that will be committed to the battle (i.e., be on line) throughout the day's fighting. The on-line units of the attacker are assumed to search for opposing units. Depending upon the search capabilities of the attacking units, as well as upon the numbers of attacking and defending units on line, some fraction of each side's on-line maneuver units come into contact with the opposition. Those units of the attacker and defender which contact enemy units then attempt to further localize (locate) them. The ability to locate the enemy is treated as a function of the separation distance between the units so that, as the attacker

closes upon the defender's position, a larger part of the enemy's force becomes accurately located. Direct fire is aimed at units that have been accurately located. Fire from support units may be brought to bear upon all contacted infantry maneuver units. However, the actual effectiveness of supporting fire is treated as a function of the number of enemy located; it is assumed that increasing information regarding the enemy's location results in increasing accuracy with which fire from support units can be directed onto his positions.

(U) As a result of each side contacting, locating, and firing upon one another's forces, losses are sustained by both sides. The model assumes that each side can control the rate at which they are incurring losses by managing the separation distance. That is, if one side's forces are suffering heavy casualties, they can mitigate this by increasing the separation distance between them and opposing units (i.e., by retreating). The maximum percentage of its force that a side is willing to lose to realize an objective (e.g., continue advancing) is termed its "threshold" attrition rate.

(U) To summarize, daily movement of the FEBA is associated with the actual attrition rate of opposing forces relative to their threshold levels. If the actual attrition rate is less than threshold levels, forces advance or hold ground; if it is greater, forces yield ground. The threshold levels of attrition rate are a function of the past casualty history of the on-line units. The actual attrition rates are a function of a) the size and composition of opposing forces, b) the search capability of attacking maneuver units, c) the ability of both forces to locate targets and bring fire to bear on those units in contact, and d) the effectiveness of direct fire and fire from support units in destroying located targets. The ability to locate targets as well as the effectiveness of direct fire is a function of separation distance between units in contact. Thus, the average separation distance between units in contact determines attrition, and the attempts to control this attrition by varying the separation distance results in FEBA movement.

(U) The level of aggregation of the model is consistent with division and corps-size engagements. Since actual division composition in terms of the numbers of battalions per division tends to vary, the actual bookkeeping of the model is in terms of battalion types rather than divisions. Infantry battalions, mechanized infantry battalions, and tank battalions are three model elements. (TOE's of each battalion type for each national participant may vary, however, and need not conform to current battalion organizations.)

D. GROUND FORCE ALLOCATION LOGIC

(U) Decision rules are used to control certain facets of the ground combat force activities at the front. In particular, the rules and methodology of this logic control the selection of offensive/defensive postures at each of the sectors, the allocation of reserve battalions and replacements to the sectors, and the allocation of battalions into and out of a pool of "fought-out" units.

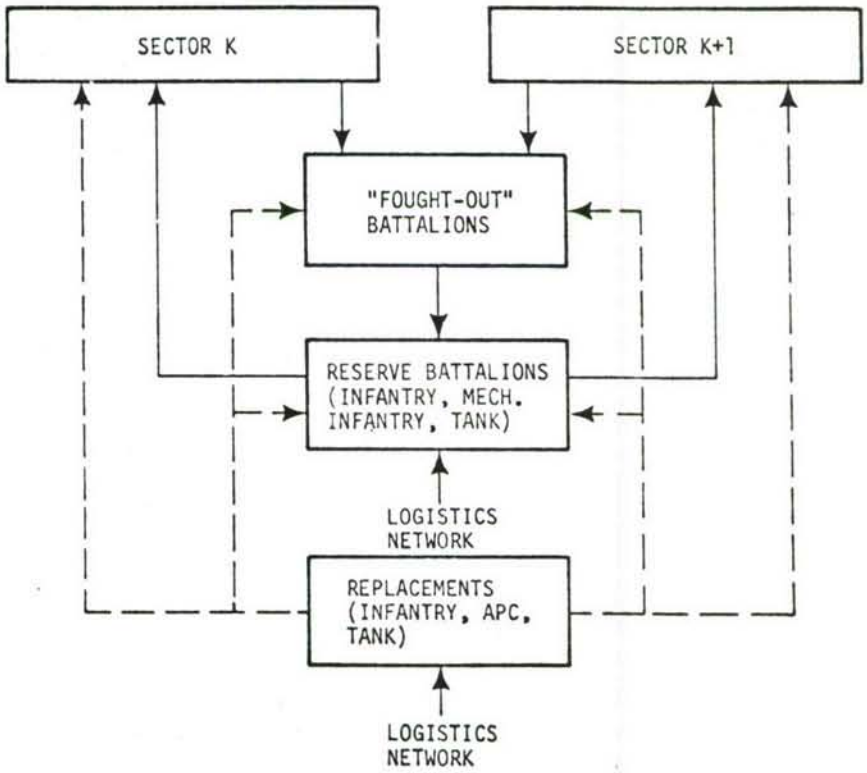
(U) The basic elements of the allocation logic are shown in Exhibit 15. Infantry, mechanized infantry, and tank battalions can be "on-line" in either of two combat sectors, in a pool of "fought-out" units for rest, or in reserve status. Battalions get into reserve status by either emerging from the logistics network (i.e., new divisions entering the forward area of the combat zone) or after resting in the pool of "fought-out" units. As presently configured, the model does not include shifting of battalions from one sector to the other by any means other than rotation through the pool of "fought-out" units.

(U) In addition to the reserve battalions, there are pools of infantry, APCs, and tanks that are used to replace combat losses in the battalions. They may be sent either to the battalions "on line" in the combat sectors or to the battalions in reserve and in the pool of "fought-out" units. Replacement troops are identified with a particular national participant and may be allocated to "on-line," reserve, or "fought-out" battalions only for that participant. Replacement APCs and tanks are identified by type, although not with any particular participant, and enter the reserve, "fought-out," and "on-line" battalions in proportion to the need of each participant as a fraction of the overall need (by type). Tanks and APCs in battalions that are removed from "on-line" status remain associated with a particular participant.

(U) The ground force allocation calculations are the last set of calculations made in assessing the results for each day of combat. Within the model, the order of calculation is:

EXHIBIT 15 (U)

MULTIPLE SECTOR GROUND FORCE ALLOCATION



1) Calculation of the number of battalions in each combat sector that are to enter the pool of "fought-out" units.

2) Allocation of individual infantry, APC, and tank replacements to the battalions "on line" in the sectors and to the reserve and "fought-out" battalions.

3) Calculation of the number of "fought-out" battalions that are returned to reserve status.

4) Selection of offensive/defensive postures for the opposing sides in each sector for the following day.

5) Allocation of reserve battalions to the combat sectors.

Each of these topics is discussed briefly below and more fully in Volume II of this report.

1. Battalions Becoming "Fought-out"

(U) An assumption that frequently is made in combat modeling -- although difficult to verify quantitatively -- is that units sustaining casualties lose combat effectiveness and can, at sufficiently high levels of losses, become totally combat ineffective. It is also typically assumed that the attacking force loses effectiveness more rapidly, as casualties accrue, than the defending force.*

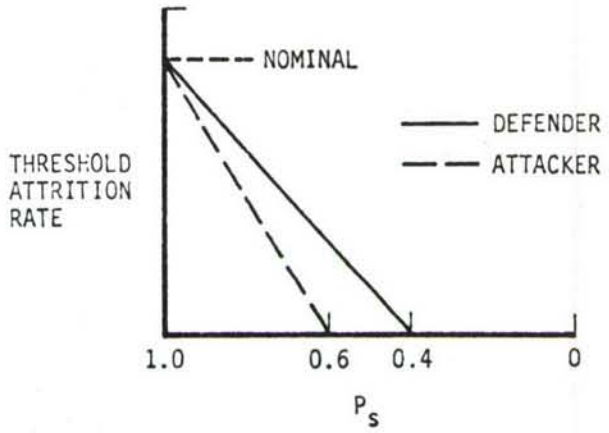
(U) Recent investigations documented in Reference 1 suggest that the cumulative probability of survival of the original members of the combat units serves as a good criterion for assessing combat ineffectiveness. The data indicate that a value of probability of survival (P_s) of 0.40 is descriptive of withdrawal of units on defense as being combat ineffective. While the data are less conclusive for attacking units, a value of $P_s = 0.60$ is assumed in this discussion to be descriptive of loss of combat effectiveness for attacking units.**

(U) This loss of effectiveness is represented in the Ground Combat Assessment Model as a modifying factor on the threshold attrition rate of the battalions to hold and acquire territory. The threshold attrition rate of the units is assumed to be linearly degraded as the cumulative probability of survival of the units is decreased due to combat losses, as depicted on the next page. This assumption sets the threshold attrition rate of fresh units at a nominal level and results in decreasing thresholds and hence decreasing battle casualties over the course of several days as the cumulative probability of survival decreases.

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*A well-known example is included in "Computerized QUICK GAME: A Theater-Level Combat Simulation," which was developed by Research Analysis Corporation. Curves developed by the Army War College are used indicating zero effectiveness for defending and attacking divisions at division-level casualties of 33 percent and 21 percent, respectively.

**The user of Lulejian-I may vary the input values of these two variables to test the sensitivity of results to them.



(U) As the threshold attrition rate of a battalion decreases, it should be considered as a likely candidate for removal to the pool of "fought-out" units for recuperation after which it can be reallocated as a fresh reserve unit with the nominal threshold attrition rate.

(U) In the Lulejian-I Model the methodology accounts for a distribution of cumulative probability of survival among the on-line battalions of a given participant and type. There is also accounting for a distribution of personnel and equipment strength which is assumed correlated with the distribution of cumulative P_s. When battalions are removed to the pool of fought-out units, those with the least strength and lowest cumulative P_s are the ones chosen for removal.

2. Allocation of Replacements

(U) Infantry, APC, and tank replacements enter the replacement pool from the logistic network. These can be, as specified by the model user, allocated to various locations of the front line area. Four basic options are available to the model user:

1. Pure unit replacement policy. All replacements are sent to the reserve battalions where they are used to increase the average strength of

the battalions. If there are still excess replacements, they are retained in the replacement pool. They are never used to replace losses in battalions "on line."

2. Modified unit replacement policy. All replacements are first sent to the reserve battalions. Any excess replacements are sent to the pool of "fought-out" units. If all reserve and "fought-out" battalions are at TOE strength, any excess replacements are sent to the battalions on line.

3. Modified individual replacement policy. All replacements are first sent to the on-line battalions in the combat sectors. Any excess replacements (all battalions on line at TOE strength) are sent next to the battalions in reserve, and then to the "fought-out" battalions (if the reserve battalions are TOE strength).

4. Pure individual replacement policy. All replacements are sent to the on-line battalions in the combat sectors where they are used to increase the average strength of the battalions. If there are any excess replacements (all battalions on line at TOE strength), they are retained in the replacement pool.

(U) Individual infantry replacements are split between infantry and mechanized infantry battalions. Infantry troops are associated with a particular national participant, and are allocated to the on-line, reserve, and "fought-out" battalions of that participant only. Likewise, each national participant uses only certain types of APCs and tanks (see Exhibit 13), and the APCs and tanks are allocated accordingly.

(U) Under the different policies, replacements are allocated according to need. The total number of vacancies -- in each sector, or for different participants for armor, or for different types of battalions for infantry troops -- is calculated and replacements are allocated in proportion to these vacancies. The amount of vacancy is the number of battalions times the difference between their TOE strength and actual average strength. This increases the average strength of the battalions on line. It does not affect the cumulative probability of survival of the original members of the on-line battalions, on which the resolve (acceptable attrition rate) is based; however, it does aid dilution of further attrition.

3. "Fought-out" Battalions Entering Reserve

(U) After a period of recuperation time, of length specified by the user, the "fought-out" battalions become eligible for reserve status where they can be used again as fresh battalions. Equations for returning "fought-out" battalions to reserve status were derived heuristically to approximate the retention of "fought-out" battalions in the pool to rest for t_r days.

(U) It is assumed that t_r days of rest are required when battalions come into the pool of "fought-out" units at a cumulative probability of survival equal to a "critical" probability of survival (PS_{crit}). A battalion entering the pool of "fought-out" units with a cumulative probability of survival less than the "critical" probability of survival requires more than t_r days in the pool of "fought-out" units to recover to full combat effectiveness.

(U) The user-inputted values for t_r, and PS_{crit}, may vary by side, national participant, and type of battalion.

4. Selection of Postures

(U) Three basic postures are included in the model: attack, hold (nominally a hasty defense), and delay. The postures in each sector for the initial day of combat may be input by the user, or optimized among a limited set of user-inputted choices. On subsequent days the selection of postures is governed by the logic which follows. As a result of the logic, there are three situations that can occur: an attack against a hold posture, an attack against a delay posture, and neither side attacking (both sides defending; a "static" sector).

(U) Certain information is used in determining postures. This information deals with the current status of the sector under consideration; the result of the day's activity, if any; and the effect of activity in the adjacent sectors on the sector flanks. In certain cases, the posture decision can be made independent of information from the adjacent sectors.

(U) A flank is considered to be "exposed" for a certain side in a sector if the section of flank between the sector FEBA and the FEBA in the adjacent sector is shared with forces from the opposing side. When the flank length (F_1, F_2) is equal to or greater than a certain amount (F_{crit}), the flank is considered to be critically exposed to lateral activity from the adjacent sectors.

(U) An attack is considered to be successful if the resulting FEBA movement in the sector is positive, or zero, in the direction of the attack. The flank lengths at each end of the battlefield are defined to be equal to zero. Also, when the defending force chooses to delay in lieu of a hasty defense, it is acknowledging the danger of a critically exposed flank by yielding territory more easily.

(U) Five cases represent the possible situations for each sector. The five cases vary according to whether there was activity in the sector, and the positions of the sector flanks.

One side attacked today:

I. Defender has two exposed flanks

II. Attacker has two exposed flanks

III. Each side has an exposed flank

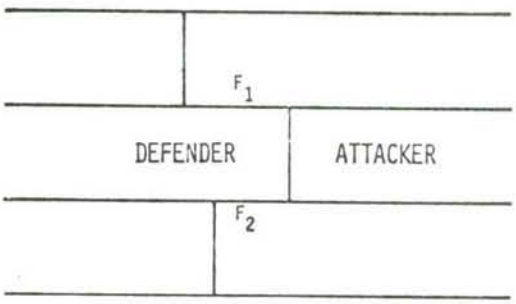
Both sides defended today:

IV. One side has two exposed flanks

V. Each side has an exposed flank

(U) Following are the rules in detail for the selection of postures in each of the five primary cases.

I. ONE SIDE ATTACKED TODAY - DEFENDER HAS TWO EXPOSED FLANKS



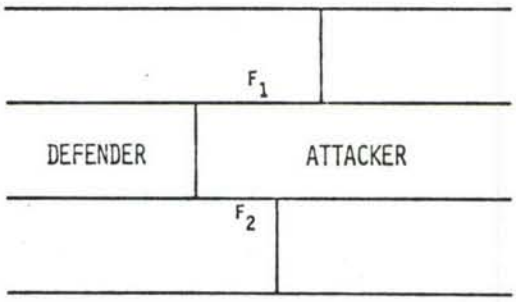
A. EITHER FLANK (F_1, F_2) IS CRITICAL:
ATTACKER WILL ATTACK, DEFENDER WILL DELAY

B. NEITHER FLANK IS CRITICAL:

1. ATTACK WAS SUCCESSFUL:
ATTACKER WILL ATTACK, DEFENDER WILL HOLD

2. ATTACK WAS UNSUCCESSFUL:
ATTACKER WILL HOLD, DEFENDER WILL ATTACK

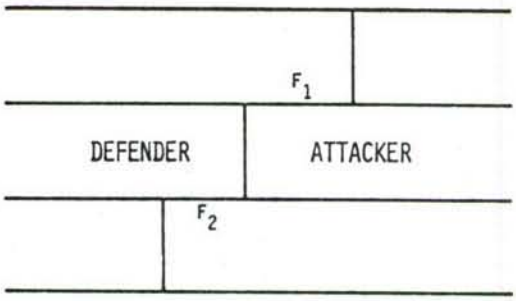
II. ONE SIDE ATTACKED TODAY - ATTACKER HAS TWO EXPOSED FLANKS



A. ATTACK WAS SUCCESSFUL:
ATTACKER WILL ATTACK, DEFENDER WILL HOLD

B. ATTACK WAS UNSUCCESSFUL:
BOTH SIDES WILL HOLD

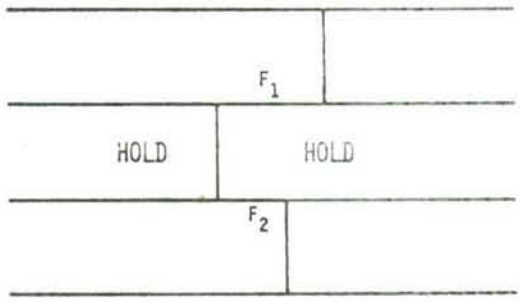
III. ONE SIDE ATTACKED TODAY - EACH SIDE HAS AN EXPOSED FLANK



A. DEFENDER'S EXPOSED FLANK IS CRITICAL:
1. ATTACK WAS SUCCESSFUL - ATTACKER WILL ATTACK
   a. FEBA MOVEMENT IN ADJACENT SECTORS IS IN DIRECTION OF ATTACK - DEFENDER WILL DELAY
   b. OTHERWISE, DEFENDER WILL HOLD
2. ATTACK WAS UNSUCCESSFUL - BOTH SIDES WILL HOLD

B. DEFENDER'S EXPOSED FLANK IS NOT CRITICAL:
1. ATTACK WAS SUCCESSFUL - ATTACKER WILL ATTACK, DEFENDER WILL HOLD
2. ATTACK WAS UNSUCCESSFUL:
   a. FEBA MOVEMENT IN ADJACENT SECTORS IS IN DIRECTION OF ATTACK - BOTH SIDES WILL HOLD
   b. OTHERWISE - ATTACKER WILL HOLD, DEFENDER WILL ATTACK

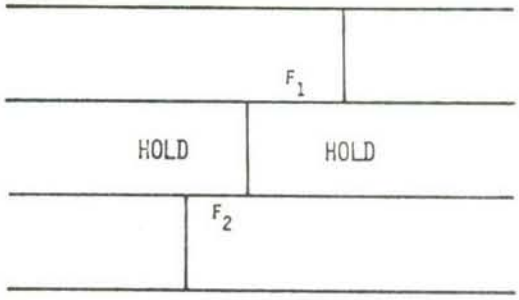
IV. BOTH SIDES DEFENDED TODAY - ONE SIDE HAS TWO EXPOSED FLANKS



A. EITHER FLANK IS CRITICAL:
THE SIDE WITH THE EXPOSED FLANKS WILL DELAY: OTHER SIDE WILL ATTACK

B. NEITHER FLANK IS CRITICAL:
1. IF BOTH FLANKS EITHER DECREASED OR REMAINED THE SAME, THE SIDE WITH THE EXPOSED FLANKS WILL ATTACK; OTHER SIDE WILL HOLD
2. OTHERWISE, BOTH SIDES WILL HOLD

V. BOTH SIDES DEFENDED TODAY - EACH SIDE HAS AN EXPOSED FLANK



A. EITHER FLANK IS CRITICAL:
1. SIDE WITH LONGER FLANK WILL DELAY; OTHER SIDE WILL ATTACK
2. IF FLANKS ARE EQUAL, BOTH SIDES WILL HOLD

B. NEITHER FLANK IS CRITICAL:
1. BOTH SIDES WILL HOLD, IF BOTH FLANKS INCREASED, BOTH DECREASED, BOTH REMAINED THE SAME, OR IF ONLY ONE FLANK INCREASED, AND THE OTHER DID NOT CHANGE.
2. IF ONE FLANK DECREASED AND OTHER REMAINED THE SAME, SIDE WITH DECREASED FLANK WILL ATTACK: OTHER SIDE WILL HOLD
3. IF ONE FLANK DECREASED AND OTHER INCREASED, THE SIDE WITH THE DECREASED FLANK WILL ATTACK: OTHER SIDE WILL HOLD

(U) In general, it will be to the attacker's advantage to split his forces unequally over the sectors, in effect massing his forces in one or more sectors. This occurs both because of the nature of the Ground Combat Assessment Model equations and because of the advantage of "dragging along" an adjacent sector when the defending force goes into the delay posture in that sector. If the attacker masses too heavily, though, his attack in the other sectors may fail (not gain ground) and result in the possibility of a successful counter-attack.

5. Allocation of Reserve Battalions

(U) The allocation of reserve battalions is governed by the offensive/defensive postures to be used on the following day, the FEBA movement in the sectors as a result of today's combat, and the initial deployment of forces to the sectors. Allocation is done individually by side and national participant, with battalions of a certain participant being sent only to sectors in which their forces are permitted. A user-inputted variable specifies the fraction of reserve battalions which may be deployed on each day of combat.

(U) If a national participant's forces are going to attack in all relevant sectors (ones in which the participant is permitted) on the following day, or are going to be defending (hold or delay) in all relevant sectors, then the reserve battalions are allocated in proportion to the deployment of forces on the initial day of combat.

(U) If a participant is not attacking in all relevant sectors or is not defending in all relevant sectors on the following day, then the deployment of forces is made in proportion to today's FEBA movement in each sector. A fraction of the deployable reserves (user specified) is allocated to the sectors in which the FEBA movement was negative today, and the remainder are allocated to the sectors in which the FEBA movement was positive. The user may thereby select the extent to which success or failure is reinforced.

(U) If reserves are allocated in proportion to the FEBA movement in the sectors, then the allocation is dependent on certain other criteria. No reserve battalions are sent to a sector in which both sides will be in a defense posture (hold-hold) on the following day, or to a sector in which the friendly forces will be in a delay posture against an attack.

E. THE RESOURCE ALLOCATION ALGORITHM

(U) The Lulejian-I model was constructed to provide an improved methodology for addressing force mix and force level problems. The model replicates a tactical theater-level campaign of specified duration (number of days). The major resources of both sides are allocated "optimally" at each decision point in the campaign. The Resource Allocation Algorithm (or simply the Algorithm) is used to determine which allocations at each decision point are "optimal." In the discussion of the Algorithm's purpose and operation the following terms are used.

(U) A "decision point" is a point in time during the campaign at which each opponent chooses an allocation of his major resources. That allocation is used each day until the next decision point. At the users option, the number of days between successive decision points may be a few as one or as many as there are days in the campaign. The number of days between successive decision points may also vary from decision point to decision point. For example, in examining a 60-day campaign, a user may allow for a decision point every 3 days during the first 18 days, followed by a decision point every 6 days during the next 30 days, followed by a single decision point for the final 12 days: a total of 12 decision points. Computation time increases with the number of decision points.

(U) An "allocation" of major resources consists of: 1) the percentage of average theater input capacity devoted to bringing in each of three items, general supplies, vehicles, and engineering supplies; and 2) the two major tactical aircraft mission areas to be emphasized until the next decision point. In addition, at the first decision point of the campaign an "allocation" includes the sectors in which massing of ground forces will occur.

(U) A number of "allocation choices" may be specified by the model user as inputs. At each decision point, the allocation chosen is selected from the "allocation choices." There is no inherent limit to the number of choices specified; however, at most 18 aircraft allocation choices may be specified in the present configuration. Computation time increases with the number of choices.

(U) "Current resources" are those which are available at the decision point under examination. "Residual resources" are those resources which remain after assessments are made of attrition of current resources for each day between the decision point being examined and the next decision point.

(U) The "immediate value of current resources" is measured by the area gain which occurs on days between the decision point being examined and the next decision point. The "future value of residual resources" is measured by the area gain which occurs between the next decision point and the end of the campaign. The "total value of current resources" is the sum of the "immediate value of current resources" and the "future value of residual resources."

(U) In order to distinguish between opponents and their allocation choices, one opponent is referred to as "Blue" and the other as "Red." In the remaining discussion it is assumed that Red is the stronger opponent and is capable of achieving a net gain of territory over the duration of the campaign. Blue's objective is to minimize that gain; Red's objective is to maximize the gain.

(U) For each allocation which Red may choose at a particular decision point, there is an allocation which Blue may choose at that decision point which minimizes the "total value of current resources." That choice of allocation by Red which results in the maximum "total value of current resources" under the assumption that Blue always chooses to minimize, is Red's "optimal" allocation at that decision point. In the Lulejian-I model one of the possible optimization options has Red "announce" his choice of allocation at the decision point being examined in advance of Blue's selection of an allocation at that point. Blue's "optimal" allocation in this case is exactly the one Red assumes for Blue, i.e., the one which minimizes "total value of current resources," given Red's choice. The solution obtained by this methodology is termed "enforceable by Red." It should be noted that under this option Red would only be obliged to announce his current allocation choice; his choices for future decision points might depend on how Blue responds.

(U) The roles of "announcer" and "responder" may be switched to determine a solution "enforceable by Blue." This requires selection of a different optimization option by the user. When the two solutions thus obtained are the same, it is called "mutually enforceable." Two other options allow the user to fix either Red or Blue allocations and allow the opposing side to optimize against them. The solution would not necessarily be "enforceable," but could illuminate possible good responses to hypothesized opposition doctrine.

(U) In order to understand the purpose for, and operation of, the Algorithm the following facts must be considered:

a) The allocations which are "optimal" for Blue and Red at a given decision point depend on the specific mix of current resources at that decision point.

b) The specific mix of residual resources, which become "current resources" at the next decision point, depends on the allocations chosen by Red and Blue at the current decision point.

c) "Optimal" choices of allocations at future decision points depend on the specific mix of residual resources resulting from choices of allocations made at the current decision point.

From a), b), and c) one can observe that "optimal" future allocations depend on current allocations.

d) "Optimal" current allocations depend on the "total value of current resources," which depends in part on the "future value of residual resources," and

e) The "future value of residual resources" depends on future allocations.

From d) and e) one can observe that "optimal" current allocations depend on future allocations. These facts, when combined, lead to the overall observation that "optimal" current allocations depend on "optimal" future allocations which depend on "optimal" current allocations..

(U) The Resource Allocation Algorithm used in the Lulejian-I Model is an iterative technique which starts with arbitrary choices of Red and Blue allocations at each decision point and converges to "optimal" allocation

choices at each decision point. The operation of the Algorithm is illustrated in the following example.

(U) Consider a campaign with three decision points, ordered in time, first, second, and third:

a) Arbitrary choices of Red and Blue allocations are assigned for each decision point by the moder user.

b) The initial resources are used to determine "optimal" allocation choices at the first decision point. Since "optimal" choices depend on both the immediate value of current resources and the future value (second and third decision points) of residual resources, the arbitrary allocation choices are used to calculate the future value of residual resources for each pair of current Red and Blue choices evaluated.

c) The residual resources from the "optimized" first decision point are used to determine "optimal" allocations at the second decision point. The arbitrary choices for the third decision point are used to calculate the future value of residual resources.

d) The resources remaining at the third (final) decision point are used to determine "optimal" allocation choices for Blue and Red at that decision point. Since there are no future decision points, the "optimal" allocations depend only on the residual resources from the second decision point.

(U) At this stage of the Algorithm process a new pair of Red and Blue "optimal" allocation choices for each decision point has been obtained. If the new choices differ from the original arbitrary choices, then either Red or Blue, or both, have improved their allocations. In this event, a new (reverse pass) iteration is begun, using the updated allocation choices rather than the arbitrary ones:

e) Returning tc the second decision point and using the residual resources from the first decision point, "optimal" allocation choices are determined. The "optimal" allocations from Step d) are used to calculate the future value of residual resources.

f) Continuing back to the first decision point, "optimal" allocations of the initial resources are determined. The "optimal" allocations for the second and third decision points, as obtained in Steps c) and d), are used to determine the "future value of residual resources."

(U) If the new choices at the end of the reverse pass differ from the set of choices at the end of the forward pass, a new cycle is begun with Step b), above. If there have been no changes in allocation choices after a complete forward or reverse pass, the process has "converged." That is, the allocation choices at each decision point are "optimal" with respect to the "optimal" allocation choices at every other decision point. The collection of "optimal" allocation choices represents a consistent set of optimal allocations.

SUMMARY PRESENTATION OF THE RAND TALLY-TOTEM THEATER LEVEL MODEL

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SUMMARY

The primary analytical tool in Rand's study of tactical airpower in NATO contingencies was war gaming in the form of open map exercises aided by computer programs. To perform such war gaming, initial orders of battle for both NATO and Warsaw Pact forces hypothetically positioned them in Central Europe. Aircraft were identified by type and number on each airbase, and ground forces were identified by unit strength within grids of 10 km by 10 km squares overlaying the region. Each ground unit was characterized both by a combat capability measure related to its firepower and by the number of its vehicles within each of four classes. Air and ground plans of action were developed for both sides on the basis of two scenarios devised in our study: Alpha, in which the NATO forces were on the defensive; and Beta, in which NATO took the offensive. The ground-force plans included the attacker's general objectives, intended routes of advance, and desired end-positions; also identified were the defender's defensive positions, fallback plans, and counterattack plans; and, finally, the schedules of both sides for bringing reserve units into action were established. Air plans included the schedules for introducing augmentation aircraft, the types of air-delivered weapons to be used, and, for the Pact, a stable and reasonable policy for allocating available air sorties among four types of air missions. NATO's air allocation policy was the focal point of our study; many disparate policies were examined over many scores of war games.

The value of different equipment, postures, and uses of NATO tactical air was assessed by our study in terms of the outcomes of the air battles and the ground battles, and the interaction between them. These hypothetical outcomes were obtained by the use of the two computer programs described in this report.

The TOTEM computer program simulates two-sided, conventional land warfare at the regimental level of detail. It is a player-interactive device developed at Rand over a period of years and used here and at other research organizations for general-purpose force studies. Aspects

of the land battle simulated in TOTEM include the following: the principal geographical features and the terrain of the battle region; various attack and defense options for both sides; various defensive postures; differences in combat capability among the ground units involved; and destruction of combat capability by ground and air action. Various types of combat actions that may occur include a meeting engagement, an attack of a hasty field defense, an attack of a deliberate field defense, an attack of a prepared defense position, the withdrawal of forces from combat, the containment of forces through encirclement, and positional warfare.

TOTEM employs a rectangular grid overlaying the combat theater. The individual areas formed by the grid (termed quads) were chosen to have dimensions of 10 km by 10 km for the Alpha and Beta series of games. Each quad possesses terrain and defensive posture identifications. Ground units are aggregated within a quad and each resulting unit's location is identified in terms of its distance and direction, along one of eight major compass headings, from the quad center. Forces can be moved and attached to other units or detached from larger units. Casualties and movement rates are taken from input tables; both rates are functions of the relative combat capability of the units and the type of engagement. Movement rates also vary with the type of terrain; movement occurs along the same eight compass headings.

The TOTEM program aggregates activities into periods of time--6 hours in this study--called cycles. At the beginning of each cycle, the TOTEM player, guided by campaign plans and by the TOTEM printout of the results of earlier cycles, tentatively introduces new orders to ground units on both sides and applies the TALLY-generated ground-attack sorties for the current cycle and for a number of subsequent cycles. He then makes a new TOTEM run to extend the combat action; in this manner, by repeatedly executing partially overlapping runs, the TOTEM player moves the war forward in time. The TOTEM program furnishes a comprehensive cycle-by-cycle history of the game play in the form of tabulations and stylized maps which give such information as the status of units, the location and outcome of engagements, and the effects of air attacks.

The conflict between the opposing air forces was simulated by a player-interactive program called TALLY, which embodies a two-sided, expected-value mathematical model of the air war. TALLY produces both a running account of surviving aircraft and a time-dependent schedule of ground-attack sorties that the ground-warfare player applies as he interacts with TOTEM. These sorties are targeted against armored vehicles in specific ground units. They directly affect the land battle by producing vehicle casualties (thereby decreasing firepower) and by inhibiting the movement of reserves, and they indirectly affect it in several ways. Changes in air equipment, posture, and allocation policy thereby produce changes in the course of the ground fighting; measures of the air/land-battle outcome thus help to reveal the relative merit of tactical air options.

The TALLY computer program thus quantifies the interactions between the air forces of the two sides. In using TALLY, the single player interacts with the program at short, regular intervals of time termed cycles--coincident with TOTEM cycles. The main action of the TALLY player is to allocate to various air missions in each cycle the total available sorties for each side. Then, on the basis of the number and type of aircraft currently at each airbase, such previously specified factors as the sortie/abort/jettison/attrition rates for each type of aircraft on each type of mission, and the effectiveness of each aircraft type when used in each mission type, the TALLY program computes the expected-value outcomes of various force interactions and maintains an accounting of the changes of air resources in the current cycle as the basis for beginning the next cycle.

The play of TALLY and the application of ground-attack sorties in TOTEM depend on weather considerations. Each play involves a particular day-by-day weather sequence chosen before the game. In the study reported here, four alternative 15-day weather sequences were used to investigate the sensitivity of the outcomes to weather factors. To this end, Central Europe was divided into ten weather zones, within which the weather for each game cycle was determined by the specified weather sequence. Each zone thereby acquired for each cycle a ceiling and visibility combination pertaining to air operations. This combination in turn implied a most effective ordnance delivery method for each

aircraft type on each mission that could be flown. These in turn determined both the attrition suffered by the delivering aircraft and the effectiveness of the delivered ordnance.

This report does not purport to be a complete user's manual for the TOTEM and TALLY programs. Nevertheless, it does provide a highly detailed description of both simulation devices, including illustrative input and output material. The actual (classified) input and output information associated with the Alpha and Beta game series is presented in the previously mentioned reports of this study.

I. INTRODUCTION

This report provides a descriptive record of TOTEM and TALLY, two computer programs that were the principal analytical tools employed in the Alpha and Beta series of hypothetical war games conducted within the Project RAND Tactical Studies Program.[1-4] Both computer programs are two-sided, expected-value models of conventional combat.* Each requires a single player who controls the program at regular intervals of game time. As will be described in the following section, TOTEM has evolved at Rand over a period of years to facilitate studies of tactical force structure; it deals with land forces at about the regimental level, operating over terrain that has been modeled on a grid of rectangles, which were 10 km by 10 km in the Alpha and Beta series of games. TOTEM's simulation of land combat reflects such aspects as the geography and terrain of the area involved, the capability of the units in the ground forces, the various attack options and defense postures of both sides, the attrition caused by ground and air action, and the movement of ground units.† By contrast, TALLY was devised primarily to augment TOTEM as a source of tactical air inputs to the latter program. As will be described in detail later, TALLY is fundamentally a program for the allocation of tactical air sorties, wherein the player at regular intervals of game time is permitted to assign the then-available supply of sorties among four mission types according to chosen allocation policies, the status of the two air forces, and the weather over the ground-battle and enemy-target zones. Two of the missions--airbase attack and air defense--directly deplete the strength of the opposing air force, but at the cost of attrition to the aircraft performing the missions; the other two--close air support and mobility interdiction--directly diminish

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*Since TOTEM and TALLY are expected-value models, the user does not obtain (probabilistic) confidence ranges for the outcomes of play. Rather, to investigate the stability of his results, he must replicate plays while varying crucial parameters.

†The TOTEM model does not expressly simulate supply and intelligence operations, but some of their important effects are incorporated in its rules and inputs.

the capabilities of the opposing land force units, again at the cost of attrition. In all cases air force attrition depends upon the ordnance-delivery mode, which in turn depends upon the weather in the zone containing the target area.

The play of TALLY for a specific study case precedes the play of TOTEM. A principal output of TALLY is a schedule of each air force's close-air-support and mobility-interdiction sorties arriving at targets in each interval of game time. The TOTEM player applies these air attacks as the TOTEM game proceeds, each successive application reflecting such factors as the current status of the land engagements, the weapon systems carried by the arriving aircraft, and the same limitations imposed by weather in various geographical zones as were used in TALLY. The main link between TALLY and TOTEM, then, is that the TALLY player provides a time-dependent supply of weather-related close-air-support and mobility-interdiction sorties that the TOTEM player uses, subject to the same weather restrictions, to affect the land combat. A second link is that TOTEM information of ground forces threatening or overrunning airbases can be fed back into TALLY, which carries data on individual airbases.

This report is not a complete user's manual for the TOTEM and TALLY programs. Nonetheless, it provides highly detailed descriptions of these simulation devices as they were used in the Alpha and Beta series of war games. The discussion of the two is separated for convenience: The initial sections of this report present a general description of TOTEM and an explanation of its basic elements, the following sections of the main text give a general description of TALLY and the mathematical formulation of its basic elements, Appendix A and its two annexes deal with the implementation of TOTEM and its play by means of the IBM 360/65 computer, and, finally, Appendix B and its annex describe how TALLY is implemented on the JOHNNIAC Open Shop System (JOSS*) and provides an illustrative printout of a TALLY play.

Other reports of the Alpha and Beta series of games contain descriptions of the classified data inputs to TOTEM and TALLY, discussions of those plays,[1-3] and a development of weather inputs.[4]

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*JOSS is the trademark and service mark of The Rand Corporation for its computer program and services using that program.

II. GENERAL DESCRIPTION OF TOTEM

TOTEM is a dynamic, expected-value computer model that portrays two-sided land combat and is programmed for the IBM 360/65 computer. The model was first developed in 1966 for use in a Rand study of tactical force structure. It was developed at about the same time as the Computerized Quick Game Model[5] of the Research Analysis Corporation, later known as the ATLAS model.[6] After its initial use, TOTEM was also used in a study by the Special Studies Group of the Joint Chiefs of Staff, in Rand studies* of Korean defense posture, Turkish defense posture, and a hypothetical campaign in Burma, and in a planning study for a United Nations training exercise in Korea.

During the development of TOTEM a series of manual games was run and the (unpublished) results were found to compare closely with those of a Department of the Army study and a Joint Chiefs of Staff study. The fact that the TOTEM model used relative combat capabilities of the opposing sides (e.g., firepower scores) as the index of ground-force strength and applied data derived or developed from Army manuals† or Army research agency studies suggested that TOTEM results be compared with actual combat outcomes. A study was made of the early days of the Korean War (1950), including a rather detailed examination of historical data on the size, capabilities, deployments, and campaign plans of the forces involved. These factors were used in a TOTEM simulation. The (internally published) results indicated that TOTEM reproduced the timing and movement of the forces quite well. Casualty rates could not be compared, however, because the available historical

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*See, for example, C. Wolf, Jr., et al., *Korean Force Postures, Regional Security, and Military Assistance Policy* (U), The Rand Corporation, RM-5130-ISA, March 1967 (Confidential) and W. A. Johnson, et al., *Force Planning for MAP Recipients: A Comparison of Ground Force Postures for Turkey* (U), The Rand Corporation, RM-5320-ISA, October 1967 (Confidential).

†See, for example, *Maneuver Control*, Department of the Army Field Manual FM 105-5, April 1964.

data were incomplete. A subsequent (unpublished) comparison of TOTEM with the Battle of the Bulge in World War II also showed reasonably close agreement.

As TOTEM was used in the Alpha and Beta series, forces are depicted at about the regimental level, and terrain is modeled on a grid of 10 km by 10 km squares.* The model reflects the following features of combat:

- The general geography of the conflict area--the land areas, water areas, major rivers, etc.
- The terrain in the conflict area, in terms of its effect on the rate of movement of ground forces.
- The force sizes (or index of capability) of the various ground units involved.
- Various attack options for the two sides (these influence the rate of advance).
- Various defense postures (these influence ground-combat casualties, unit rates of advance, and the "hardness" of the ground targets for air-delivered ordnance).
- The casualties that each unit suffers from ground action and air action.
- The noncombat and combat movements of the individual units.

An engagement occurs in TOTEM whenever units of the opposing forces are in the same quad. Several types of combat actions or engagements are included. These are:

- Meeting engagement (initial phase).
- Attack of a hasty field defense.
- Attack of a deliberate defense.
- Attack of a prepared position (three alternative degrees of preparation are allowed).
- Attack of a fortified zone.
- Withdrawal of forces.

---

*TOTEM has a sufficiently general structure to permit any size of ground-unit aggregation and of grids; the two should, of course, correlate with each other.

- Containment of forces through encirclement.
- Positional warfare.

In addition to these combat actions, "automatic" routines can be added to the program. For example, units in a hasty field defense can be allowed to automatically improve their defense posture to that of a deliberate defense if they are not driven out of the hasty field defenses after a specified period of time. In each combat action the casualties are determined, based on the relative combat strengths of the attacking and defending forces in the tactical area (grid rectangle or quad) and the type of engagement, and the movement of the battle line is determined from these same two factors plus the type of terrain in the quad.

The rate of movement of unopposed forces is a function of the type of terrain and the transportation systems assumed. Reserve forces of any size can be moved from one location to another and can be attached to or reinforce other units. Similarly, forces of any size can be detached from larger units or disengaged from enemy units in the attack or defense of a tactical area and moved to another location.

Ground-combat casualty rates and movement rates of forces in contact are input to the model in the form of tables, where they are tabulated as functions of the factors listed above. For the Alpha and Beta series of games, the casualty and movement rates were derived from Department of the Army publications, from gaming manuals of the Research Analysis Corporation and the Combat Operations Research Group, and from other sources such as historical analyses of selected military campaigns.* Ground-force casualties and, for moving, unengaged units, movement delay caused by air attacks† are determined from cycle-by-cycle allocations of ground-attack sorties to individual ground units and from sortie effectiveness numbers, also input in tabular form.‡

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*These references (mostly of a "special handling" nature) are listed in an internal publication by M. G. Weiner.

†See Annex 2 to Appendix A.

‡These inputs must, of course, be based on appropriate analyses of the ordnance, delivery method, and target.

Combat intervals of 6 hours were the basic time unit used in the model for the Alpha and Beta series, with the first cycle taken to begin at midnight and each day assumed to consist of two "day" cycles and two "night" cycles. (Two daylight cycles of 6 hours here were consistent with air operations of nominally two sorties per day per aircraft. Shorter or longer combat intervals can be used if appropriate changes are made in the input tables of casualties and movement rates.) For each 6-hour cycle, the computer routines produce a complete summary of the situation, which includes tabular summaries of the forces engaged, the type of action, the current and cumulative casualties, the extent of any advance of the battle line, the locations of the engaged and unengaged units within the tactical region, and status summaries for all units. A stylized map of the theater, indicating the location and strength of each unit and the type of combat action in which it is engaged, may be provided for designated cycles.

In the Alpha and Beta series, TOTEM was operated in what may be characterized as an iterative mode. That is, once the situation, forces, and military objectives were defined and reflected in TOTEM's initial input factors, the program was run for a limited number of cycles with unit action orders and close-air-support sorties input for each cycle. The user would then review the results of this run, changing action orders and rerunning as many cycles as necessary to achieve conformity with a set of tactical rules of play* and with the attack plan, and would also extend the new run to include later cycles. In such an interrupted, forward-and-back manner, 10 to 20 runs might be required to cover a 60-cycle period of warfare.

In summary, TOTEM is a moderately aggregated simulation of large-scale land combat. The computer's basic role is to maintain the current locations, statuses, and objectives of individual units to evaluate the outcomes of individual engagements on the basis of input tables, and to provide summaries and stylized maps depicting current force status.

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*Annex 1 to Appendix A gives the tactical rules of play used in the Alpha series. Such standardized procedures were helpful in producing comparability among the various plays.

III. BASIC ELEMENTS OF TOTEM

This section describes the basic elements of the TOTEM model. The interested reader may then move to Appendix A for a highly detailed presentation of the application of TOTEM--including the player's initial planning that enables a ground-force campaign to be adapted to simulation, the preparation of the various input cards, the responses to the cycle-by-cycle progress of the campaign, and the interpretation of the various outputs.

GEOGRAPHY AND TERRAIN

In TOTEM, the combat theater is divided into tactical areas consisting of rectangles (quads) formed by an overlaid grid (see Fig. 1). These quads are the basis for the level of aggregation, and their dimensions should approximate the frontage of the organizational level played; that is, if the units involved are to be evaluated primarily at the regiment or brigade level then the dimensions should be roughly a regimental frontage. The current upper limit to the maximum number of quads is $36 \times 42 = 1512$. A convenient quad size for resolution at the regiment level is a 10 km by 10 km square; this is the quad size used in the Alpha and Beta series.

Several descriptive parameters are entered by the player for each quad and are thereafter printed out on stylized maps of the combat theater (see Fig. 2). These inputs are described below.

Terrain: The type of terrain (and the offense/defense force ratio) determines the rate of advance of an attacking force against the various defensive postures and the movement rate of unopposed forces and reserves. In each quad the terrain is classified as one of five categories reflecting the relative ease or difficulty of force movements and of an attacking force's advancement. Rough definitions* of these categories are:

*A quantitative system for classifying terrain for use in TOTEM has been developed by T. T. Connors of The Rand Corporation.

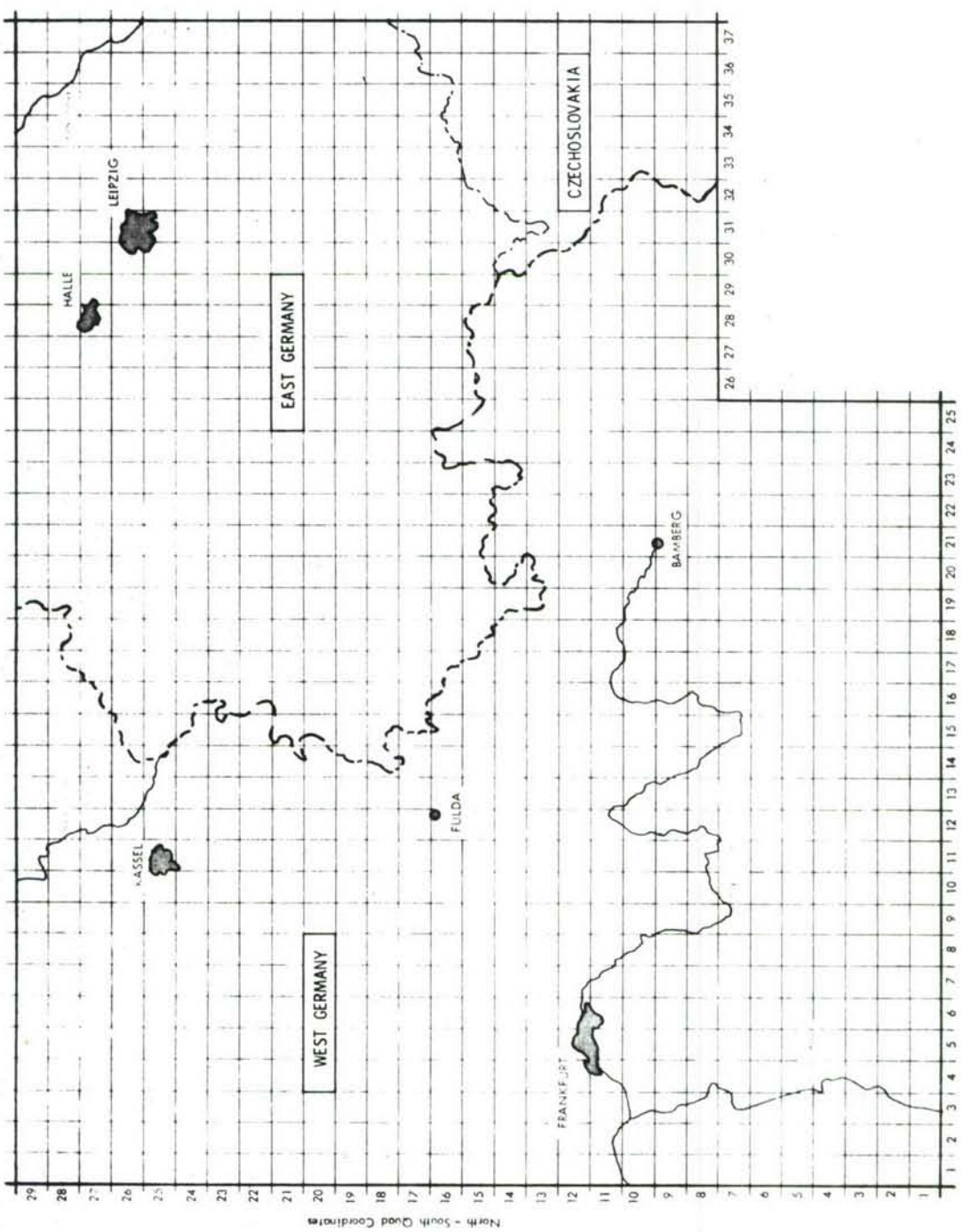


Fig. 1—Combat theater of the Alpha and Beta scenarios with the overlaid TOTEM grid

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
18	+POOR	+POOR	+POOR	+POOR	+POOR	+FAIR	+FAIR	+FAIR	+GOOD	+FAIR	+POOR	+POOR	+FAIR	+FAIR	+18
18	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+18
17	+POOR	+POOR	+POOR	+POOR	+POOR	+FAIR	+GOOD	+FAIR	+FAIR	+FAIR	+FAIR	+POOR	+POOR	+POOR	+17
17	+HFD	+HFD	+HFD	+DD	+DD	+DD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+17
16	+POOR	+POOR	+POOR	+FAIR	+FAIR	+GOOD	+FAIR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+16
16	+HFD	+HFD	+HFD	+HFD	+HFD	+DD	+DD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+16
15	+POOR	+POOR	+POOR	+POOR	+FAIR	+GOOD	+FAIR	+POOR	+POOR	+FAIR	+POOR	+POOR	+POOR	+POOR	+15
15	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+DD	+DD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+15
14	+POOR	+POOR	+POOR	+FAIR	+POOR	+GOOD	+FAIR	+FAIR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+14
14	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+DD	+DD	+HFD	+HFD	+HFD	+HFD	+HFD	+14
13	+POOR	+POOR	+POOR	+POOR	+FAIR	+GOOD	+FAIR	+FAIR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+13
13	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+HFD	+DD	+DD	+HFD	+HFD	+HFD	+HFD	+13
12	+POOR	+POOR	+POOR	+FAIR	+POOR	+FAIR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+12
12	+HFD	+HFD	+HFD	+HFD	+HFD	+PA	+PA	+HFD	+HFD	+DD	+DD	+HFD	+HFD	+HFD	+12
11	+VP	+VP	+FAIR	+FAIR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+VP	+POOR	+POOR	+11
11	+HFD	+HFD	+HFD	+PA	+PA	+HFD	+PA	+HFD	+HFD	+HFD	+DD	+DD	+HFD	+HFD	+11
10	+GOOD	+GOOD	+VP	+FAIR	+FAIR	+FAIR	+FAIR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+10
10	+PB	+PB	+PB	+HFD	+HFD	+HFD	+HFD	+PA	+HFD	+HFD	+HFD	+PA	+DD	+HFD	+10
9	+GOOD	+GOOD	+VP	+EXC	+POOR	+FAIR	+GOOD	+POOR	+POOR	+POOR	+POOR	+POOR	+FAIR	+POOR	+ 9
9	+HFD	+HFD	+PB	+HFD	+HFD	+HFD	+HFD	+PA	+HFD	+HFD	+HFD	+HFD	+PA	+DD	+ 9
8	+GOOD	+GOOD	+VP	+EXC	+FAIR	+FAIR	+POOR	+POOR	+POOR	+VP	+POOR	+POOR	+FAIR	+POOR	+ 8
8	+HFD	+HFD	+PB	+HFD	+HFD	+HFD	+HFD	+PA	+HFD	+HFD	+HFD	+HFD	+DD	+DD	+ 8
7	+GOOD	+GOOD	+VP	+GOOD	+FAIR	+POOR	+POOR	+POOR	+POOR	+POOR	+FAIR	+POOR	+FAIR	+FAIR	+ 7
7	+HFD	+HFD	+PB	+HFD	+HFD	+HFD	+HFD	+HFD	+PA	+HFD	+HFD	+HFD	+HFD	+DD	+ 7
6	+GOOD	+GOOD	+VP	+FAIR	+FAIR	+POOR	+POOR	+POOR	+POOR	+POOR	+FAIR	+POOR	+POOR	+GOOD	+ 6
6	+HFD	+HFD	+PB	+HFD	+HFD	+HFD	+HFD	+HFD	+PA	+HFD	+HFD	+HFD	+HFD	+DD	+ 6
5	+POOR	+GOOD	+VP	+VP	+GOOD	+POOR	+POOR	+POOR	+POOR	+POOR	+FAIR	+POOR	+POOR	+FAIR	+ 5
5	+HFD	+HFD	+PB	+HFD	+HFD	+HFD	+HFD	+HFD	+DD	+HFD	+HFD	+HFD	+HFD	+HFD	+ 5
4	+VP	+EXC	+EXC	+VP	+FAIR	+POOR	+POOR	+POOR	+POOR	+POOR	+FAIR	+POOR	+POOR	+POOR	+ 4
4	+HFD	+HFD	+PB	+HFD	+HFD	+HFD	+HFD	+HFD	+DD	+HFD	+HFD	+HFD	+HFD	+HFD	+ 4
3	+VP	+FAIR	+FAIR	+VP	+FAIR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+FAIR	+ 3
3	+HFD	+HFD	+PB	+HFD	+HFD	+HFD	+HFD	+PA	+DD	+HFD	+HFD	+HFD	+HFD	+HFD	+ 3
2	+POOR	+FAIR	+VP	+GOOD	+GOOD	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+ 2
2	+HFD	+HFD	+PB	+HFD	+HFD	+HFD	+HFD	+HFD	+PA	+HFD	+HFD	+HFD	+HFD	+HFD	+ 2
1	+GOOD	+GOOD	+VP	+FAIR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+POOR	+ 1
1	+HFD	+HFD	+PB	+HFD	+HFD	+HFD	+HFD	+HFD	+PA	+HFD	+HFD	+HFD	+HFD	+HFD	+ 1
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	

TERRAIN AND DEFENSE MAP

NOTE: Entries within quads are terrain type (upper) and existing defense posture (lower).

Fig. 2—A TOTEM printout of a 180 km by 140 km section of the combat theater in the Alpha series

- Excellent--Prevailing conditions permit free movement of tracked vehicles in all directions at speeds determined only by the nature of the moving units.
- Good--Prevailing conditions permit free movement of tracked vehicles in any direction at speeds slightly less than maximum.
- Fair--Prevailing conditions moderately hinder progress or restrict direction of movement. The cause of the restrictions may be bogs, lakes, or canals, local forests and shallow valleys, or steep slopes and intrenched streams.
- Poor--Prevailing conditions severely hinder cross-country movement of tracked vehicles. Restrictions may be caused by forested hills, heavy forests on plains, lakes, bogs, or ditches, mountains or steep forested hills.
- Very poor--Prevailing conditions permit speeds slightly below rates set for "poor" conditions.

Existing Defenses: Existing prepared defensive positions or barriers are input for each quad. (The definitions of the several types of defensive positions are given below.)

Major Physical and Political Features: Physical features, such as major rivers, waterways, and mountain ranges, and political features, such as national boundaries and major cities, may be input and printed out on the maps. These provide a means of orientation on the stylized maps.

REPRESENTATION OF THE GROUND FORCES

Friendly and enemy units may be input at such different levels as regiment, brigade, division, and corps. In general, inputs for the Alpha and Beta series were at the regiment and brigade level. However, the authorized number of men and the weapon mix varies considerably from country to country for similarly designated units, and actual combat strength varies from unit to unit. In TOTEM all forces of a side

in a quad are aggregated into one unit and each unit must be input with an initial value that represents a common measure of combat strength. The measure of combat strength used in the Alpha and Beta series was a combat capability (CC) index* based upon the Indexes of Firepower Potential described in Ref. 7. In addition to the CC index, the initial numbers of tanks, armored vehicles (primarily armored personnel carriers (APCs)), self-propelled artillery, and other wheeled vehicles are also input for each ground unit.

FORCE OBJECTIVES AND UNIT ACTIONS

Force objectives enter TOTEM through a set of space- and time-dependent instructions to the forces in the quads, as will be described below. These instructions control the maneuvers of the forces and, together with rules governing the model's use of the instructions and the progress of the combat engagements, provide a simulation of the campaign plan.

The basic time interval in TOTEM is called a cycle--6 hours in the applications here. New instructions to the units, introduction of reserves into the theater, and the assignment of ground-attack air sorties to units or quads are input between cycles.

Associated with the forces in a quad is an "action" instruction indicating the mission of the forces during the cycle. New action instructions need be inserted only when there is a change of status. For example, as units are introduced into the theater, they are automatically told to "defend" the quads they initially occupy; they will continue in this defensive posture until new mission or action instructions are given. TOTEM embodies six mission or action instructions: (1) M, move; (2) A, attack; (3) B, attack and contain; (4) D, defend; (5) W, withdraw; and (6) S, detach (split). The instructions A, B, and D direct a force with a specified serial number, or in a specified quad, to advance toward a specified quad, or in one of eight compass directions, and if enemy forces are encountered, to attack, attack and contain, or defend. Instruction W is given only to an engaged unit; it causes

*For details of the index and CC values as used in Alpha and Beta, see Ref. 2 and Ref. 3, respectively. TOTEM games, including one in the Beta series (Ref. 3), have also been played with personnel strength as the metric.

the unit to disengage a specified portion of the force and sends that portion to a specified quad. The M (move) instructions can be used to move an unengaged unit to a new location without becoming engaged en route or to join a force with a specified serial number to a friendly force either with a specified serial number or in a specified quad; the S (detach or split) instruction can be used to partition a force into two or three units and to deploy the newly created unit(s) elsewhere. If forces in a quad are not in contact with an opposing force, they will proceed to execute their action instruction as given; if they are in contact, the action instructions for the two opposing forces jointly determine the type of combat engagement that ensues, under rules presented below. Further information on the six action instructions is also given below.

Move (M): This instruction is designed to move unengaged forces around enemy forces and thus avoid combat. It should be used only when such action is possible; its purpose usually is to join one friendly force to another.

Attack (A): A force told to attack will attempt to move toward the indicated quad or in the indicated direction whether or not it is in contact with the enemy.

Attack and Contain (B): This instruction causes an attacking unit to split into two parts. One part--the "containing" force--remains in its current quad, with the entire defending force in that quad. The size of the containing force is a function of the size of the defending force; in the applications here, the containing force was required to be 1.5 times the size of the defender. The balance of the attacking force attempts to advance in the manner specified, just as though it had received an attack instruction.

Defend (D): A unit instructed to defend will position itself in the specified quad and assume the defensive posture associated with that quad. If an opposing unit occupies the quad or enters the quad in a subsequent cycle, an engagement ensues. If a unit of the same side occupies the quad or enters the quad in a subsequent cycle, the two units will merge and thereafter be treated as a single entity.

Withdraw (W): An instruction to withdraw causes an engaged unit, or a specified portion of the unit, to disengage and move away from the opposing force to a specified quad. If the withdrawal is to involve

only a part of the unit, the size of that part is specified, either as an absolute value or as a fraction of the original unit. A unit ordered to withdraw will proceed without hindrance to the designated quad unless it encounters an on-going engagement en route. In the latter event, the withdrawing unit will be absorbed by its engaged colleague.

Split (S): A force may be ordered, by a single instruction, to detach one or two units. Each new element thus formed is given a new order to attack, attack and contain, defend, withdraw, or move. The residual part of the original unit continues to perform the mission of its last previous instruction. If desired, the residual part may be given new orders in the same cycle of play by inserting a new instruction after the instruction to split.

Overriding Orders: A unit that receives two or more different orders in a single cycle will comply with the last order read into the model in the sequence of orders for that cycle.

Reserves and Reinforcements: Forces not in contact are considered to be in a reserve posture. Reserve units may be placed in the quads prior to the start of the conflict or may be introduced any time during the conflict. Such forces receive casualties only from air action specifically directed against them. A unit that enters a quad as a reinforcement takes the quad position of the reinforced unit. These reinforcements become effective as a fighting element at the end of the cycle during which they enter the quad.

When a force not in contact with the enemy moves into a quad occupied by an enemy during a cycle, an "initial engagement" ensues (see below, p. 16). Subsequent events for the forces in the quad depend upon the action instructions of the two forces.

DEFENSIVE POSTURES

Combat engagements between attacking and defending forces are evaluated on the basis of the defending force's defensive posture. The defensive posture may be one of several types, depending upon the types of defensive works constructed and the protection offered by natural features. The defense type for each side and each quad is

input to specify the initial condition for the campaign (see Fig. 2). The following definitions characterize various defensive postures used in TOTEM.

Hasty Field Defense (HFD): Unless another defensive posture is specified, this defense is assumed during contact with an enemy or when contact is imminent. The defensive force deploys to take tactical advantage of local terrain features. Since this is a tentative tactical deployment, the position has no specified depth. The defensive force may be forced to withdraw through a continuous series of these positions and, therefore, may be in this posture for an extended period. The position will be strengthened as the situation and time allow. Artificial obstacles may be erected on a limited basis. For example, mines, as available from combat loads, are frequently placed on routes of likely armored advances.

Deliberate Defense (DD): This defense presumes a defensive position developed, at rates specified for each quad, from a hasty field defense position, by occupying troops using primarily locally available materials. Foxholes would be dug, gun emplacements provided, and obstacles erected to the extent that the tactical situation and materials allow. Mines and barbed wire would be available in limited quantities. As a means of describing the relative value of the position to the defender as an obstacle to the advance of an attacker, it may be assigned an effective depth expressed in kilometers. Since a position is an obstacle only when it is defended, its effective depth depends on the number of occupying troops. Theoretically, a position could have an infinite number of effective depths. For practical purposes, the number of depths used must be held to a minimum. For example, a position occupied by a regiment could be assigned an effective depth of 10 km and the same position occupied by a lesser force could have an effective depth of, say, 4 km. Effective depths should be specified for each TOTEM use (see Table 1).

Prepared Position A (PPA or PA): This is a preplanned position that is constructed over an extended period (the period should be specified for each game). Men, weapons, and materials are protected with heavy timber and earth works and, to a lesser degree, concrete structures. Barriers to combat vehicles are installed and fire coverage is

preplanned. An extensive communication system is an installed part of the position. The factors that would determine effective depths should be selected within the concepts given in the discussion of a deliberate defense (see Table 1*).

Table 1

ILLUSTRATIVE TOTEM PREPARED-DEFENSE DEPTHS[a]

(In km)

Defending Force Size		Defense Type				
		Deliberate Defense	Prepared Position			Fortified Zone
			A	B	C	
BLUE	≤ 200CC	6.0	6.0	6.0	6.0	6.0
	> 200CC	9.0	9.0	9.0	9.0	9.0
RED	≤ 150CC	6.0	6.0	6.0	6.0	6.0
	> 150CC	9.0	9.0	9.0	9.0	9.0

[a]After an attack has penetrated to the indicated defense depth within a quad, it then encounters only HFD as the defensive posture for the remainder of the quad.

Prepared Position B (PPB or PB): This is a preplanned position that is constructed over a prolonged period as an extension of a "prepared position A" or sited and designed to enhance the protection provided to a defensive force by natural features, such as the lesser rivers of Europe (the Weser and Ems among others) and the rugged terrain of northern South Korea. Effective depths should be selected within the concepts given in the discussion of a deliberate defense (see Table 1).

Prepared Position C (PPC or PC): This is a preplanned position that is constructed over a protracted period as an extension of a "prepared position A" beyond the status of a "prepared position B" or sited and designed to enhance the protection provided to a defensive force by a major natural terrain feature, such as the Rhine River. Effective

*Illustrative tables in this report contain arbitrarily modified data so as to avoid security classification.

depths should be selected within the concepts given in the discussion of a deliberate defense (see Table 1).

Fortified Position (FORT): This is a defense based on a preplanned position constructed prior to the start of hostilities. Heavy protection, principally concrete, is provided for men, weapons, and materials. Elaborate fire-control and communication systems are an integral part of the position. Strong barriers to combat vehicles are included.

Of the foregoing positions, the two strongest defensive postures--prepared position C and fortified position--did not appear in the Central European locale of the Alpha and Beta scenarios.

Depth of defense depends on the time available for its preparation and on the strength of the defending force. Currently, each type of defense may have two defense depths: One depth would be assigned when the defense is fully manned, as measured by the number of CCs in the quad; the other would be assigned when the defense is less than fully manned (see Table 1).

If a force is in a hasty field defense, its posture will be improved to that of a deliberate defense after it remains in the quad a specified period, which was four 6-hour cycles in the Alpha and Beta series.

ENGAGEMENT TYPES

All combat is evaluated at the quad level. Opposing forces occupying a quad simultaneously are assumed to be engaged in some form of combat. Since the forces occupying a quad are generally large, a number of what would be "small unit" actions in real life are thus necessarily aggregated in the simulation into a "large unit" evaluation of the combat outcome. The combat engagements are of several different types, as follows.

Initial Engagement: This is the first contact between two opposing forces and generally involves only their covering forces. Primarily, both sides are developing intelligence on which to base plans for the next cycle. This type of action occurs during the first cycle of contact and precedes all other postures. It is also applicable to

renewed contacts after earlier engagements which were broken off by maneuver.

Attacks in the Absence of Prepared Defense Positions: This is combat after the first cycle of an engagement in the absence of any prepared defenses, that is, where the defensive posture is HFD.

Attacks Against Prepared Defense Positions: This is combat after the first cycle of an engagement, with the defending side in one of the following postures:

- Deliberate defense.
- Prepared position defense A.
- Prepared position defense B.
- Prepared position defense C.
- Fortified position.

Inactive Positional: Both sides have assumed a defensive posture through a "defend" action instruction, either because the attacking unit has reached its instructed destination, or because the offense/defense force ratio has fallen below a designated level. Action is limited to patrolling and minor probes to determine the enemy's size, locations, and probable intentions. Casualty rates are low and stem primarily from patrol clashes and skirmishes incidental to probing actions.

Containment: A force in contact with an enemy becomes "contained" when an attacker has sufficient force advantage to break through the defensive position, while leaving behind a portion of his force to contain the defender. A containment is the action that takes place after a force has become contained. Conceptually, the contained force is pinned in place and eventually destroyed, its members killed or captured.

Withdrawal: A force withdraws all or part of its elements from contact with the enemy. The conditions under which this is allowed must be defined. The conditions may include a penalty, such as leaving a part of the force as a rear guard.

Table 2 illustrates the determination of engagement type, as a function of action type, for a defensive unit in a HFD posture.

Table 2

ILLUSTRATIVE DETERMINATION OF TOTEM ENGAGEMENT TYPE AS A FUNCTION OF TOTEM ACTION TYPE[a]

(Defensive unit is in HFD posture)

Action Type of Smaller Force	Action Type of Larger Force					
	M	A	B	D	W	C
M (Move)	HFD[b]	HFD	HFD	POS	WITH	POS
A (Attack)	HFD	HFD[c]	HFD[c]	HFD	WITH	HFD
B (Attack + Contain)	HFD	HFD[c]	HFD[c]	HFD	WITH	HFD
D (Defend)	HFD	HFD	HFD	POS	WITH	POS
W (Withdraw)	WITH	WITH	WITH	WITH	WITH	WITH
C (Contain)[d]	HFD	HFD	HFD	CON	WITH	CON

[a]The engagement types determined here are used to enter a table of engagement outcomes (see Table 3, p. 20).

[b]Read throughout table as an engagement between an attacking unit and a unit in a hasty field defense posture. This would automatically change to DD, PA, PB, PC, or FORT if the defensive unit were in a higher-order defensive position.

[c]If both forces have attack orders, the smaller is assumed to be the defender.

[d]The C action is not user-specified but is generated within the TOTEM program. (See p. 12 for an explanation of "containing.")

TACTICAL AIR STRIKES

Tactical air strikes in support of the ground battle can be represented in TOTEM in several ways. Close-air-support sorties against engaged units can be manually assigned against specific units or against the units in specified quads, or sorties can be assigned automatically by TOTEM according to a prescribed rule, that is, in proportion to the product of the size of an engaged enemy unit and the friendly-to-enemy force ratio of the engagement in which it is involved. In the latter case, units or quads can be designated not to receive air attacks. Mobility-interdiction sorties against reserve units must be manually

assigned against specified units or against the units in a specified quad. The mining of roads by air-delivered ordnance may also be simulated by manually directing mine-laying sorties against specified quads.

The procedures for assessing the effects of air strikes in producing ground-unit casualties and retarding ground-unit movement are described below.

CASUALTY AND MOVEMENT ASSESSMENT

A casualty and movement assessment is made for each ground unit for each cycle. Casualties from ground-to-ground combat and from air strikes are determined separately and summed to give the total casualties for the cycle. The direction of movement for unengaged units depends upon the action instruction of the units, and the movement rate for unopposed units is a tabular function only of the type of terrain traversed;* however, unengaged units may be delayed by mobility-interdiction strikes in direct attack or by minefields in the path of the ground unit as explained below. The movements and movement rates of engaged units are tabular functions of several factors: the action instructions of the opposing units; the force ratio; the defense posture of the defending units; and the terrain.†

Ground-Combat Casualties: Engaged ground units suffer casualties from ground combat at a rate dependent upon the engagement type, the ratio of the ground-force strengths (as measured by the beginning-of-cycle CCs of the two opposing forces or other measures of interest‡), and the defensive posture of the defending force (see Table 3).

Ground-Unit Casualties Caused by Air Attacks: A casualty assessment is made for each ground unit assigned air-attack sorties. For the Alpha and Beta series the desired targets for air attacks were the tanks, self-propelled artillery pieces, and APCs. Ten percent of the

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*See discussion on p. 23 and Table 5, p. 23.

†See discussion on p. 22 and Table 3.

‡Applications of TOTEM have thus far used CCs as the index of ground-force strength, with one exception when personnel strength was used. In the further description of TOTEM, whenever CCs appear as the index, the reader may regard it as illustrative.

Table 3

ILLUSTRATIVE TOTEM INPUT INFORMATION USED FOR CASUALTY AND MOVEMENT ASSESSMENT

(Engagement type[a]: attack against HFD)

Casualties and Movement Rate	Combat Ratio[b]							
	<1	1	2	3	4	5	6	>6
Offense casualties[c]	0.85	1.10	2.10	3.10	3.10	3.10	3.10	3.10
Defense casualties[c]	0.70	0.95	1.20	2.20	2.20	2.20	2.20	2.20
Excellent terrain movement rate[d]	0.28	0.92	1.65	3.55	5.35	7.40	9.15	13.00
Good terrain movement rate[d]	0.17	0.65	1.13	2.27	3.89	5.80	6.85	9.65
Fair terrain movement rate[d]	0.08	0.50	0.92	1.98	3.22	4.34	5.34	8.02
Poor terrain movement rate[d]	0.00	0.37	0.73	1.69	2.57	3.61	4.57	7.21
Very poor terrain movement rate[d]	0.00	0.25	0.55	1.41	1.93	2.89	3.81	4.81

[a] Similar tables exist for other engagement types, i.e., for an initial meeting engagement (IE), attack against deliberate defense (DD), attack against prepared position A (PA), attack against a prepared position B (PB), attack against prepared position C (PC), attack of a fortified zone (FORT), inactive positional (POS), containment (CON), and withdrawal (WITH). Engagement type is determined as Table 2 illustrates.

[b] Combat ratio = $\frac{\text{Attacker CCs}}{\text{Defender CCs}}$.

[c] Table entry is the loss of CCs per cycle expressed as a percent of the defense-force CCs.

[d] In units of kilometers per cycle.

trucks were assumed to be mistaken for armored vehicles and attacked. The number of vehicles of type i killed is given by a distributed form of the familiar "kill potential" equation, as follows:

$$\Delta V_i = V_i \left\{ 1 - \exp \left[- \frac{K_i SD}{V} \right] \right\}$$

where V_i = the beginning-of-cycle number of vehicles of type i. (In the Alpha and Beta series, the initial V_4 was ten percent of the total number of trucks.)

i = 1 tanks.
= 2 armored vehicles.
= 3 self-propelled artillery.
= 4 other wheeled vehicles (trucks, etc.).

$V = \Sigma V_i$.

K_i = the kill potential per sortie against target vehicle type i (a function of aircraft/weapon system type, delivery mode, defensive posture, existence of nighttime or daylight conditions) including a factor for probability of target detection (see Table 4).

S = number of attack sorties of a specified type.

D = min (1, 0.1 + CC/CC_o) is a kill potential dilution factor in terms of the current (at the beginning of the cycle) and initial (at the beginning of the game) combat capability indexes of the unit. This formulation is intended to reflect the increased difficulty in detecting live vehicles as the population of such vehicles decreases.

TOTEM keeps account of the numbers of live vehicles of each type in each unit at the beginning of each cycle. The combat capability of the ground unit attacked by air is reduced by the sum of the CCs associated with the vehicles destroyed in each cycle, those vehicle-associated CCs having been input by the user.

Table 4

ILLUSTRATIVE CLOSE AIR SUPPORT EFFECTIVENESS: KILL POTENTIAL PER SORTIE FOR TWO AIRCRAFT WEAPON SYSTEM TYPES

Aircraft/ Weapon System Type	Ground-Force Posture	Type of Vehicle Target			
		Tanks	Armored Vehicles	Self-Propelled Artillery	Other Wheeled Vehicles
BLUE 1	Attack	4.390[a,b]	4.140	4.390	5.800
	Hasty field defense	4.300	4.050	4.300	5.660
	Deliberate defense	4.210	3.970	4.210	5.540
RED 3	Attack	1.870	1.810	1.870	1.810
	Hasty field defense	1.850	1.780	1.850	1.780
	Deliberate defense	1.830	1.760	1.830	1.760

[a]The entries are the quantities K_i in the formula for ΔV_i (see p. 21).

[b]Separate values may be input for day and night operations.

Movement of Engaged Forces: The movement rate for engaged forces depends upon the action instructions of each force, the end-of-cycle, attacker-to-defender force ratio, the defensive posture of the defending force, and the terrain (see Table 3). Although not used in the Alpha and Beta series, provision is also included for the success or failure of an attack to be a random event, depending upon a "probability of success" factor as a function of force ratio and engagement type. At first contact between engaged forces, an initial engagement is assessed with no combat movement for the cycle. Subsequent engagement types depend upon the action instructions of the units and the defense posture for the defending unit (see Table 2). For engagements between two attacking units, the smaller unit is considered to be the defending force. No movement occurs for engagements between two defending units, for containments, or for positional engagements.

Unit Break Levels: As casualties mount, a critical casualty level may be reached at which the unit "breaks" and is no longer able to fulfill its mission. Each offensive unit can have a "break level" value--the level of casualties at which an attacking unit automatically goes into a defensive posture for a period of time determined by an input value. The unit break level values may be changed at the beginning of any cycle. This feature of TOTEM was not used in the Alpha and Beta series.

The Introduction and Movement of Unengaged Forces: Ground units may be brought into the combat theater and placed in any quad at the beginning of any cycle. Subsequent movements of a unit depend upon the time sequence of action instructions given to the unit; such instructions may direct the unit to move either to a given quad, in a given direction, or to join a specified friendly unit. The movement rate of unopposed units depends only upon the terrain traversed; daylight movement rates for each side and each type of terrain are inputs and nighttime movement rates are assumed to be 0.75 times the daytime rates. Table 5 illustrates unengaged movement rates.

Table 5

ILLUSTRATIVE UNOPPOSED MOVEMENT RATES

(In km per cycle)

	Terrain Type				
Force	Excellent (E)	Good (G)	Fair (F)	Poor (P)	Very Poor (VP)
BLUE	90.0	80.0	70.0	60.0	50.0
RED	85.0	75.0	65.0	55.0	45.0

Delays Imposed by Mobility-Interdiction Strikes: Unengaged ground units that are attacked by tactical air strikes suffer both casualties and movement delay. The casualty computations are the same as for engaged units; different sortie effectiveness can be simulated by using a different type of aircraft/weapon system (see Table 4). The movement delay time caused by direct air attack during a cycle is

$$D = \frac{6S - 1}{120} + \max\left[0.5, \frac{10M}{N - M}\right] + \frac{0.07M(N - 2)}{v(M + 2)}$$

where D is the movement delay in hours, S is the number of air-attack sorties received during the cycle, N is the total number of vehicles

in the quad, M is the total number of vehicles destroyed, and v is the unopposed movement rate in the quad in kilometers per hour.*

Delays Caused by Minefields: Mining attacks by aircraft were assumed to be carried out at last light against roads that appeared to be likely routes for movement of reserves.† A mined quad was assumed to be impassable at night but clear within two hours after daybreak. (Mining attacks were not performed in the Alpha series.)

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*See Annex 2 of Appendix A for a development of this formula.

†The calculation of sortie requirements for the mining attacks in the Beta series is recorded in unpublished notes.

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IV. GENERAL DESCRIPTION OF TALLY

TALLY is a user-interactive, air allocation model developed at Rand primarily to provide tactical air inputs to TOTEM, the land-combat model described earlier in this report. This two-sided, expected-value model, originally written on JOSS,* enables a single player to allocate the currently available sorties of both sides to various air missions. The specific inputs to TOTEM developed by TALLY are the expected numbers of mobility-interdiction and close-air-support sorties that survive enemy defenses, with their munitions intact, and reach their targets.

Air forces of each side are identified by aircraft type and distributed among a set of bases. Each base contains only one type of aircraft and is one of two vulnerability types, which in the Alpha and Beta series of games was identified as either a main operating base (MOB) or a dispersed operating base (DOB). The interaction of the two air forces occurs during a sequence of four-cycle days in which cycles one and four are nighttime cycles and cycles two and three are daytime cycles. At the beginning of each cycle, the program computes, and will display on request, the number of sorties of each aircraft type available for allocation during the cycle. This number is a function of the cycle (daytime or nighttime), the current inventory of the bases, an input sortie rate, and the expected disruption of base operations† resulting from airbase attacks during the preceding cycle.

By responding to TALLY requests, the player allocates the sorties to the several missions. The program computes the expected number of sorties that survive enemy defenses with munitions intact and reach their targets and the expected in-flight losses as functions of input

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*After the Alpha and Beta series of games, TALLY was adapted to the IBM 360/65 computer system and several modifications were made. It has since been made operational on the IBM 370/128 system and on the MULTICS system used by OSD. Only the system as used in the Alpha and Beta games is described here.

†As explained below, the player-specified disruption factor is the proportion by which the capability of a base to mount sorties in a cycle is diminished by an attack on that base in the preceding cycle.

jettison, abort, air-to-air attrition, and ground-to-air attrition rates. The jettison and air-to-air attrition rates are modified by TALLY as the expected number of available opposing air-defense sorties changes during a play.

For the airbase-attack mission, the expected number of armed sorties arriving at their targets is assigned by the player to specific opposing bases. At the conclusion of each cycle, TALLY computes the number of aircraft surviving at each base as a function of the airbase attacks received by the base, the expected number of aircraft caught on base during the attacks, and the expected in-flight losses suffered among the sorties generated by the base.

The first cycle executed by the program is assumed to be a "surprise-attack" cycle in which either side may be chosen as the initiator. During this cycle sorties by the side receiving the attack may be allocated only to the air-defense mission. The player may bypass the surprise-attack cycle by simply not allocating the attacker's sorties during that cycle.

One aircraft type of each side may be identified as a "special" aircraft with long-range, heavy-payload characteristics, as will be described in Sec. V.

Weather considerations enter TALLY indirectly in each cycle--that is, weather in the various zones governs the type of aircraft-ordnance-delivery modes that the player can use, where he can conduct the airbase-attack, mobility-interdiction, and air-defense missions, and whether he can apply close air support anywhere along the forward edge of the battle area (FEBA). (The same weather restrictions in each zone determine the *specific* employment of close-air-support and mobility-interdiction sorties in TOTEM at the time these sorties are assigned against individual ground units, either manually by the player or automatically by the program.)

The printed output of a TALLY cycle contains the expected number of armed sorties reaching their targets, the expected number of in-flight losses for each aircraft type and each mission, and the expected number of on-base losses for each aircraft type. Cumulative totals that include past cycles may also be requested by the player.

In the JOSS version of TALLY, the player must interact with the program throughout the battle. Changes to the input parameters may be made at the beginning of each cycle. The program contains procedures which readily enable the user to introduce new bases, augment the base aircraft inventories, change the type of aircraft located at the bases, and change other parameters (such as sortie rates) as the battle progresses.

V. BASIC ELEMENTS OF TALLY

This section describes the basic elements of TALLY. The interested reader may then move to Appendix B and its annex for a highly detailed presentation of how TALLY is operated on JOSS and for an illustrative case.

THE PROGRAM CYCLE

The TALLY program divides each day into four cycles. For the games of the Alpha and Beta series, the first cycle was taken to begin at midnight and was followed by two daylight cycles and finally by a second night cycle. The number of daylight hours (denoted U) is a player-provided input; this quantity is used by TALLY only in the computation of airbase occupancy factors, i.e., the fraction of aircraft currently occupying a base that are "at home" when the base receives a daylight attack

The first cycle of play is unique. A surprise attack is presumed to occur as the onset of air combat. Among his initial inputs, the player identifies the day on which air action begins (denoted by D and an identification number), the identification number of the starting (surprise) cycle (denoted C),* and the identification number of the side that initiates the surprise attack (i = 1 denotes BLUE; i = 2 denotes RED). The option of allocating aircraft in the first cycle to missions other than air defense is not given to the side receiving the surprise attack. (As noted earlier, the surprise-attack cycle may be bypassed by simply not allocating the initiator's sorties during that cycle.)

AIRCRAFT CHARACTERISTICS

The air forces of the two sides may be composed of a number of

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*In TALLY, cycles of play are identified as c = 1, 2, 3, and 4 for each day of play; in TOTEM, cycles are numbered consecutively for the entire course of play, e.g., the final cycle on the fifteenth day would be c = 60.

aircraft types.* The player specifies the number of types as the quantity T_i, where i = 1, 2 denote BLUE and RED, respectively. Two sets of player-provided input factors characterize the aircraft. The first set of factors, which applies to each aircraft type k of side i, is the following:

$R_{i,k}$ = sortie rate (sorties per day).

$u_{i,k}$ = sortie length (hours).

$a_{i,k}$ = abort rate.

$j_{i,k}$ = beginning munition jettison rate for airbase-attack sorties.

$A_{i,k,1}$ = ground-to-air attrition rate for airbase-attack sorties against MOBs (this rate may be modified for attacks against DOBs; a weighted-average rate should be used if both MOBs and DOBs are attacked in a cycle).

$A_{i,k,2}$ = beginning air-to-air attrition rate for airbase-attack sorties.

$P_{i,1,k}$ = the expected fraction of aircraft, located on an enemy MOB, destroyed by a single type-k attacking aircraft.

$P_{i,2,k}$ = the expected fraction of aircraft, located on an enemy DOB, destroyed by a single type-k attacking aircraft.

$g_{i,k}$ = an indicator that a type-k aircraft is an air-defense aircraft ($g_{i,k}$ = 1) or is not an air-defense aircraft ($g_{i,k}$ = 0).

The second set of factors is common to all aircraft types of side i, namely:

o_i = attrition rate for air-defense sorties.

e_i = beginning munition jettison rate for close-air-support sorties.

$r_{i,1}$ = beginning air-to-air attrition rate for close-air-support sorties.

$r_{i,n}$ = ground-to-air attrition rate for close-air-support sorties with weapon-delivery mode n = 2, 3, ... (The

*Size limitations on the TALLY program are given in Appendix B.

player defines the number of distinct values to enter and, during the allocation phase of each cycle, identifies which entry is to be used for each aircraft type allocated to the close-air-support mission.)

Q_i = the number of mobility-interdiction zones* that may be attacked.

$h_{i,1,q}$ = beginning munition-jettison rate for mobility-interdiction sorties flown by nonspecial aircraft types of side i against zone q.

$h_{i,2,q}$ = beginning munition-jettison rate for mobility-interdiction sorties flown by the special aircraft type of side i against zone q.

$H_{i,1,1,q}$ = ground-to-air attrition rate for mobility-interdiction sorties flown by the nonspecial aircraft types of side i against zone q.

$H_{i,2,1,q}$ = ground-to-air attrition rate for mobility-interdiction sorties flown by the special aircraft type of side i against zone q.

$H_{i,1,2,q}$ = beginning air-to-air attrition rate for mobility-interdiction sorties flown by nonspecial aircraft types of side i against zone q.

$H_{i,2,2,q}$ = beginning air-to-air attrition rate for mobility-interdiction sorties flown by the special aircraft of side i against zone q.

THE SPECIAL AIRCRAFT TYPE

Each side may include one special aircraft type in its force. (The intent here is to reflect the availability of a long-range, heavy-payload, all-weather aircraft to the tactical air forces). The special aircraft type, which will be denoted in the subsequent discussion by the symbol $\bar{k}$, is assumed to have the following characteristics:

- A sortie rate of 1.0 per day.
- Basing in a sanctuary area (its bases are not subject to attack).

*These zones are defined and discussed later.

- No allocation to close air support.
- Unique jettison and attrition rates for its mobility-interdiction sorties.

In the Alpha and Beta series of games, BLUE special aircraft could be allocated only during the two nighttime cycles, and RED special aircraft could be allocated only during the two daytime cycles. Available sorties not flown during the first of the two operating cycles could be used during the second.

THE AIRCRAFT BEDDOWN

Each air force is distributed among a set of up to 50 bases. The TALLY player specifies the number of bases available to each side as the quantity, B_i, i = 1, 2. Then, for each base b of each side i, the player further specifies the following:

$t_{i,b}$ = the type of aircraft located at this base.
$I_{i,b}$ = the current number of aircraft at this base.
$v_{i,b}$ = the vulnerability class of the base, where $v_{i,b}$ = 1 corresponds to a MOB and $v_{i,b}$ = 2 to a DOB in the Alpha and Beta series.

The player has options of introducing new bases and of changing the current inventory at existing bases as the TALLY program proceeds cycle-by-cycle through the conflict.

THE BASE DISRUPTION FACTOR

Bases that are attacked during a cycle not only suffer losses among the aircraft caught on base but also are assumed to experience a disruption of base operations during the cycle following the attack. The magnitude of the disruption is presumed to be independent of the intensity of the attack. The base disruption factor is defined to be the expected fraction of sorties that a base could generate during a cycle but which are not generated because the base was attacked during the preceding cycle. During the input phase of the program, the user

specifies the magnitude of V, the disruption factor for bases receiving attacks during the surprise-attack cycle, and $W_{i,1}$, the disruption factor for the bases of side i receiving attacks in a cycle other than the surprise-attack cycle.

Letting $E_{i,b}$ be the base disruption factor for base b of side i during the current cycle, and defining $F_{i,b}$ to be the probability that an aircraft caught on the base survives the airbase attacks of the preceding cycle, then

$$E_{i,b} = \begin{cases} 0 & \text{if } F_{i,b} = 1, \\ V & \text{if } F_{i,b} < 1, \text{ the preceding cycle was the surprise cycle, and side i received the surprise attack,} \\ W_{i,1} & \text{otherwise.} \end{cases}$$

THE BASE OCCUPANCY FACTOR

The occupancy factor of a base is defined to be the expected fraction of aircraft operating from a base that are caught on the base by the arrival of an enemy attack. For the surprise-attack cycle, daytime or nighttime, the base receiving the attack is assumed to save, by scrambling to escape the attack, either 25 percent of its aircraft inventory or 16 aircraft,* whichever number is smaller. For other nighttime cycles, the entire current aircraft inventory is assumed to be caught on base. For other daytime cycles, the occupancy factor is expressed as a simple function of the number of daylight hours, the base disruption factor, and the sortie length, sortie rate, and abort rate of the aircraft assigned to the base.

Letting $O_{i,b}$ be the occupancy factor of base b of side i, then

$$O_{i,b} = \begin{cases} 1 & \text{if the current cycle is a nighttime cycle other than the surprise-attack cycle,} \\ 1 - \min(.25, 16/I_{i,b}) & \text{if the current cycle is the surprise cycle and i receives the attack,} \\ 1 - \dfrac{(1 - a_{i,k})(1 - E_{i,b})R_{i,k}u_{i,k}}{U} & \text{otherwise,} \end{cases}$$

*These values are set in the program but can be changed by the user.

where $I_{i,b}$ is the current inventory, $k = t_{i,b}$ is the type of aircraft located at base b, $a_{i,k}$ is the abort rate, $E_{i,b}$ is the disruption factor, $R_{i,k}$ is the daily sortie rate, $u_{i,k}$ is the sortie length, and U is the number of daylight hours.

AIR-DEFENSE MULTIPLIER

As the number of available air-defense sorties for one side changes during a game, the jettison and air-to-air attrition rates experienced by the opposing force also change. At the beginning of a game, TALLY computes $W_{i,2}$, the number of nonaborted air-defense sorties potentially available to side i during a single cycle:

$$W_{i,2} = \sum_{b \in \bar{B}_i} 0.5\, R_{i,k} I_{i,b} (1 - a_{i,k})$$

where the summation is over the set of bases $\bar{B}_i$ of side i containing aircraft types designated as air-defense aircraft, $k = t_{i,b}$ is the type of (air-defense) aircraft at such bases b of side i, $I_{i,b}$ is the *initial* number of these aircraft located at base b, $R_{i,k}$ is the daily sortie rate, and $a_{i,k}$ is the abort rate.

At the beginning of each cycle the program computes $W_{i,3}$, the fraction of $W_{i,2}$ that is currently available to side i:

$$W_{i,3} = \left[\sum_{b \in \bar{B}_i} 0.5\, R_{i,k} I_{i,b} (1 - E_{i,b})(1 - a_{i,k}) \right] \Big/ W_{i,2}$$

where the summation is over the set of bases $\bar{B}_i$ containing aircraft types designated as air-defense aircraft, $I_{i,b}$ is the *current* number of aircraft located at base b, $E_{i,b}$ is the disruption factor, and the other symbols have been defined immediately above. For the current cycle, the jettison and air-to-air attrition rates applying to the opposing airbase-attack, mobility-interdiction, and close-air-support sorties are multiplied by $W_{i,3}$ as shown below.

SORTIES TO BE ALLOCATED IN THE ALLOCATION PROCESS

Cycle Sorties

The sorties available for allocation to the four missions during the current program cycle, c, are termed the *cycle sorties*, as opposed to the *potential sorties*, defined below. (These cycle sorties reflect the disruption caused by enemy airbase attacks of the preceding cycle.) With the exception of the special aircraft type, aircraft are allowed to fly only during the daytime cycles (c = 2, 3) and no more than one-half the daily sorties, defined by the sortie rate, may be allocated during a single cycle. Cycle sorties that are available but not allocated during cycle 2 are not available for allocation during cycle 3. Thus, letting $S_{i,k}$ be the cycle sorties for type-k aircraft of side i, then for all nonspecial aircraft (i.e., $k \neq \bar{k}$),

$$S_{i,k} = \begin{cases} 0.5\, R_{i,k} \sum_{b \in B_{i,k}} I_{i,b}(1 - E_{i,b}) & \text{if } c = 2 \text{ or } 3, \\ 0 & \text{otherwise,} \end{cases}$$

where $B_{i,k}$ is the set of bases of side i containing type-k aircraft, $R_{i,k}$ is the sortie rate, $I_{i,b}$ is the current inventory, and $E_{i,b}$ is the disruption factor.

The special aircraft of each side may be allocated during either of two consecutive flying cycles, which for side 1 (BLUE) are cycles 4 and 1 and for side 2 (RED) are cycles 2 and 3. All daily sorties (at the rate of one per aircraft) are available for allocation during the first of the two consecutive flying cycles, and any sorties not allocated during that cycle are available for allocation during the next cycle.

Thus, if the current cycle is either the first of the two consecutive flying cycles or else the first of the run and the second of the two consecutive flying cycles, then

$$S_{i,\bar{k}} = \sum_{b \in B_{i,\bar{k}}} I_{i,b}$$

If the current cycle is the second of the two consecutive flying cycles for special aircraft and not the first cycle of battle, sorties that were not allocated in the preceding cycle may be allocated in the current cycle. Letting $\bar{S}_{i,\bar{k}}$ denote the cycle sorties of the preceding cycle, and letting $\bar{s}_{i,\bar{k},n}$ denote the cycle sorties allocated to the n*th* mission during the preceding cycle, if the current cycle is not the first of the run but is the second of the two consecutive flying cycles, then

$$S_{i,\bar{k}} = \bar{S}_{i,\bar{k}} - \sum_{n=1}^{2} \bar{s}_{i,\bar{k},n}$$

where n = 1 denotes airbase attack and n = 2 denotes mobility interdiction.

If the current cycle is not equal to either of the two consecutive flying cycles, then

$$S_{i,\bar{k}} = 0$$

Potential Sorties

After the player indicates his wish to allocate the cycle sorties of a side to the several missions, TALLY will display on request the current inventory, the cycle sorties, and the potential sorties for each aircraft type. Potential sorties are defined to be the sum of the current cycle sorties and the expected number of cycle sorties during the next cycle, should the side suffer no attrition and no on-base attacks during the current cycle. Letting $\hat{S}_{i,k}$ denote the potential sorties for type-k aircraft of side i, then

$$\hat{S}_{i,k} = \begin{cases} S_{i,k} + 0.5\, R_{i,k} \sum_{b \in B_{c,k}} I_{i,b} & \text{if } k \neq \bar{k} \text{ and } c = 2, \\ S_{i,k} & \text{otherwise.} \end{cases}$$

ALLOCATION TO AIRBASE ATTACK

Within the allocation process for each side, the first option presented to the program user is that of specifying the number of cycle sorties to be allocated to airbase attack. For each aircraft type not designated for the air-defense mission, TALLY requests the player to specify $s_{i,k,1}$, the number of type-k cycle sorties allocated to airbase attack. (This request is not made if the number of cycle sorties, $S_{i,k}$, is zero.) The program requires that $s_{i,k,1} \leq S_{i,k}$ and requests that the player reallocate if the condition is not satisfied. TALLY then displays $s'_{i,k,1}$, the expected number of type-k sorties that reach their targets after surviving enemy defenses, estimated by the following expression:

$$s'_{i,k,1} = s_{i,k,1}(1 - a_{i,k})(1 - W_{j,3}J_{i,k})(1 - A_{i,1,k} - W_{j,3}A_{i,2,k})$$

where $a_{i,k}$ is the abort rate, j is the opposing side, $W_{j,3}$ is the air-defense multiplier, $J_{i,k}$ is the beginning jettison rate, $A_{i,1,k}$ is the ground-to-air attrition rate, and $A_{i,2,k}$ is the beginning air-to-air attrition rate.

After the airbase-attack allocations for all aircraft types have been specified by the player, the program displays the fraction of total available cycle sorties (including air-defense cycle sorties) which have been allocated to the airbase-attack mission and then offers the player the opportunity to reallocate.

The airbase-attack sorties that survive enemy defenses and reach (i.e., that "arrive" at) their targets armed with munitions are then assigned to individual opposing bases. However, before the assignments are made, the player may request a display of the current inventories

of the opposing bases. Two types of display are available. In the first, the bases are organized into sets of bases containing the same aircraft type and belonging to the same vulnerability class. The second display presents a list ordered on current inventory for all bases of vulnerability class 1 followed by a similarly ordered list for the bases of vulnerability class 2. Examples of both types of display appear in the illustrative case in the annex to Appendix B.

For each aircraft type, the player assigns the total arriving airbase-attack sorties among subsets of the enemy bases. The type-k arriving airbase-attack sorties are taken to be divided into M_k assignments, with the m*th* assignment being against a subset of opposing bases numbering N_m bases. Denoting the expected arrivals of the m*th* assignment as y'_m, we assume each of the N_m bases is attacked by y'_m/N_m sorties. TALLY requires that

$$\sum_{m=1}^{M_k} y'_m = s'_{i,k,1}$$

(that is, that the expected number of arriving airbase-attack sorties be completely assigned) and requests that the player reassign the type-k sorties if this condition is not satisfied.

The expected loss rate for type-k sorties* of side i allocated to the airbase-attack mission, $\dot{s}_{i,k,1}$, is estimated as follows:

$$\dot{s}_{i,k,1} = (1 - a_{i,k})(1 - W_{j,3}J_{i,k})(A_{i,1,k} + W_{j,3}A_{i,2,k})$$

where $a_{i,k}$ is the abort rate, j is the opposing side, $W_{j,3}$ is the air-defense multiplier, $J_{i,k}$ is the beginning jettison rate, $A_{i,1,k}$ is the ground-to-air attrition rate, and $A_{i,2,k}$ is the beginning air-to-air attrition rate. (This formulation implies that aircraft that jettison

*In TALLY, the expected number of *aircraft* lost to attrition on each of the four types of missions is assumed equal to the expected number of *sorties* lost to attrition (see p. 43).

ordnance are able to evade air-defense attacks and thereby to avoid air-to-air attrition as well as ground-to-air attrition.)

ALLOCATION TO MOBILITY INTERDICTION

The second option within the allocation process for each side enables the player to specify the number of cycle sorties to be allocated to mobility interdiction. For each aircraft type not designated for the air-defense mission, TALLY displays the number of cycle sorties available following the airbase-attack allocation, $S_k - s_{i,k,1}$, and requests the player to assign sorties to mobility-interdiction zones. (If the number of available sorties equals zero, the assignment request is not made.)

Up to four mobility-interdiction zones can be used for each side. A mobility-interdiction zone may represent a geographic area or a set of targets. The distinguishing features of the zones are that each may have unique jettison and attrition factors that apply to attacking aircraft. Hence the zones may be used to represent areas or target sets distinguished by different levels of enroute jettison and attrition and/or different levels of effectiveness of terminal defenses.

For each aircraft type, the player assigns a number of cycle sorties to an opposing mobility-interdiction zone number. Given that M_k assignments have been made for type-k aircraft on the mobility-interdiction mission, with z_m being the zone of the m^{th} assignment and y_m being the number of cycle sorties of this m^{th} assignment, then TALLY displays y'_m, the expected number of sorties arriving at their targets, as estimated by the following expression:

$$y'_m = y_m \left(1 - a_{i,k}\right)\left(1 - W_{j,3}h_{i,n,z_m}\right)\left(1 - H_{i,n,1,z_m} - W_{j,3}H_{i,n,2,z_m}\right)$$

where $a_{i,k}$ is the abort rate, j is the opposing side, $W_{j,3}$ is the air-defense multiplier, n = 1 if k is not the special aircraft type, n = 2 if k is the special aircraft type, h_{i,n,z_m} is the beginning jettison rate, $H_{i,n,1,z_m}$ is the ground-to-air attrition rate, and $H_{i,n,2,z_m}$ is the beginning air-to-air attrition rate.

Letting $s_{i,k,2}$ be the total number of type-k sorties of side i allocated to the mobility-interdiction mission, then

$$s_{i,k,2} = \sum_{m=1}^{M_k} y_m$$

TALLY requires that the number of cycle sorties allocated be less than or equal to the number available (i.e., $s_{i,k,2} \leq S_{i,k} - s_{i,k,1}$) and requests the user to reallocate if the condition is not satisfied.

The expected loss rate for type-k sorties allocated to the mobility-interdiction mission, $\dot{s}_{i,k,2}$, is estimated as follows:

$$\dot{s}_{i,k,2} = \left(1 - a_{i,k}\right) \sum_{m=1}^{M_k} \left(\frac{y_m}{s_{i,k,2}}\right) \left(1 - W_{j,3} h_{i,n,z_m}\right)$$

$$\left(H_{i,n,1,z_m} + W_{j,3} H_{i,n,2,z_m}\right)$$

where $a_{i,k}$ is the abort rate, j is the opposing side, $W_{j,3}$ is the air-defense multiplier, n = 1 if $k \neq \bar{k}$, n = 2 if $k = \bar{k}$, h_{i,n,z_m} is the beginning jettison rate, $H_{i,n,1,z_m}$ is the ground-to-air attrition rate, and $H_{i,n,2,z_m}$ is the beginning air-to-air attrition rate.

ALLOCATION TO CLOSE AIR SUPPORT

The third option within the allocation process for each side enables the player to specify the number of cycle sorties to be allocated to close air support. For each aircraft type that is neither assigned to the air-defense mission nor is in the special aircraft type category, the player may allocate either no sorties or all of the remaining available cycle sorties, $S_{i,k} - s_{i,k,1} - s_{i,k,2}$. At the same time, the player identifies which of the several input close-air-support ground-to-air attrition rates (depending on weapon-delivery mode employed)

should be applied. (This choice is returned to TALLY by the player's response to the question "Alloc to CAS?": "0" indicates that no sorties are to be allocated; "1" indicates that all remaining sorties are to be allocated using the first ground-to-air attrition rate; "2" indicates that all remaining sorties are to be allocated using the second ground-to-air attrition rate; etc.)

If all remaining sorties are allocated, TALLY displays $s'_{i,k,3}$, the expected number of close-air-support sorties arriving at their targets, which it calculates as follows:

$$s'_{i,k,3} = \left[S_{i,k} - s_{i,k,1} - s_{i,k,2} \right] (1 - a_{i,k})(1 - W_{j,3} e_i)$$

$$(1 - r_{i,n+1} - W_{j,3} r_{i,1})$$

where $a_{i,k}$ is the abort rate, j is the opposing side, $W_{j,3}$ is the air-defense multiplier, e_i is the beginning jettison rate, $r_{i,n+1}$ is the n*th* ground-to-air attrition rate, and $r_{i,1}$ is the beginning air-to-air attrition rate.

The expected loss rate for type-k sorties of side i allocated to the close-air-support mission, $\dot{s}_{i,k,3}$, is estimated as follows:

$$\dot{s}_{i,k,3} = (1 - a_{i,k})(1 - W_{j,3} e_i)(r_{i,n+1} + W_{j,3} r_{i,1})$$

ATTRITION TO AIR-DEFENSE AIRCRAFT

After the cycle sorties of both forces have been allocated to the airbase-attack, mobility-interdiction, and close-air-support missions, the option of applying or not applying air-to-air attrition to air-defense aircraft is presented to the player, provided the current cycle is a daytime cycle and the opposing force has suffered air-to-air losses during the current cycle while performing missions other than air defense. The player responds to the question "RED AD Losses?" (or "BLUE AD Losses?") with either a "1" (yes) or a "0" (no). If the player's response is affirmative, TALLY displays the available number of cycle

sorties for each air-defense aircraft type; these aircraft, by the player's choice, are subject to air-to-air attrition. The expected loss rate for the type-k air-defense aircraft, $\dot{s}_{i,k,4}$, is calculated by

$$\dot{s}_{i,k,4} = (1 - a_{i,k})o_i$$

where $a_{i,k}$ is the abort rate and o_i is the attrition rate.

EXPECTED OUTCOMES

On-Base Risk

During the input phase of the program, the player defines $P_{j,v,k}$, the expected fraction of losses inflicted by one type-k aircraft of side j to the aircraft caught on an opposing base of vulnerability class v. We define $F_{i,b}$ to be the probability that the aircraft caught on base b of side i survive all airbase attacks during the cycle. Given that base b of side i has received $N_{i,b}$ independent attacks during the cycle and given that the n*th* attack contains y'_n sorties of aircraft type k_n, then

$$F_{i,b} = \prod_{n=1}^{N_{i,b}} \left[1 - P_{j,v_{i,b},k_n}\right]^{y'_n}$$

The expected fraction of a base's current aircraft inventory that is caught on base by the opposing airbase attack has been defined earlier to be the occupancy factor, $O_{i,b}$. If $\overline{PSB}_{i,b}$ is the probability that the aircraft stationed at base b of side i survive all airbase attacks of the current cycle and $\overline{PKB}_{i,b}$ is the probability they do not survive, then

$$\overline{PSB}_{i,b} = 1 - O_{i,b}(1 - F_{i,b})$$

$$\overline{PKB}_{i,b} = 1 - \overline{PSB}_{i,b}$$

In-Flight Risk

For simplicity in the TALLY model, the expected number of *aircraft* lost to attrition on each of the four mission types is assumed to equal the expected number of *sorties* lost to attrition, whatever the mission. (This assumption is accurate provided that attrition and sortie rates are not unduly large.) It is also assumed that of the cycle sorties from each of the bases with type-k aircraft, the fraction allocated to mission n equals the fraction of all type-k cycle sorties allocated to mission n, that is, $s_{i,k,n}/S_{i,k}$.

The expected cycle sortie loss rate for type-k aircraft of side i on mission n has been defined above as $\dot{s}_{i,k,n}$, n = 1, 2, 3, 4. If $\overline{pkf}_{i,b,n}$ denotes the probability that an aircraft on base b of side i is lost on mission n, then

$$\overline{pkf}_{i,b,n} = 0.5(1 - E_{i,b})R_{i,k}\left[\frac{s_{i,k,n}}{S_{i,k}}\right]\dot{s}_{i,k,n}$$

where $k = t_{i,b}$ is the type of aircraft at base b, $E_{i,b}$ is the disruption factor, and $R_{i,k}$ is the daily sortie rate. If $\overline{PKF}_{i,b}$ is the probability that the aircraft on base b do not survive all missions, and $\overline{PSF}_{i,b}$ is the probability that they do survive all missions, then

$$\overline{PKF}_{i,b} = \sum_{n} \overline{pkf}_{i,b,n}$$

$$\overline{PSF}_{i,b} = 1 - \overline{PKF}_{i,b}$$

Combined On-Base and In-Flight Risk

Defining $PS_{i,b}$ to be the probability that the aircraft located at base b of side i survive enemy action during the current program cycle and $PK_{i,b}$ to be the probability that they do not survive, then

$$PS_{i,b} = \overline{PSF}_{i,b}\overline{PSB}_{i,b}$$

$$PK_{i,b} = 1 - PS_{i,b}$$

The total losses on base b of side i during the current cycle can then be expressed as follows:

$$L_{i,b} = I_{i,b}PK_{i,b}$$

where $I_{i,b}$ is the current number of aircraft located at base b. The inventory at base b has thereby been diminished to:

$$I_{i,b}PS_{i,b}$$

Daily Summary

In the printed output of a TALLY run, the total losses at a base are disaggregated into on-base losses, $LB_{i,b}$, total in-flight losses, $LF_{i,b}$, and in-flight losses on the *nth* mission, $\ell f_{i,b,n}$, by means of the following assumptions:

1. The ratio of the on-base losses to the total in-flight losses equals the ratio of the on-base kill probability to the in-flight kill probability, i.e.,

$$\frac{LB_{i,b}}{LF_{i,b}} = \frac{\overline{PKB}_{i,b}}{\overline{PKF}_{i,b}}$$

2. The ratio of in-flight losses on mission n to the total in-flight losses equals the ratio of the kill probability for mission n to the kill probability for all missions, i.e.,

$$\frac{\ell f_{i,b,n}}{LF_{i,b}} = \frac{\overline{pkf}_{i,b,n}}{\overline{PKF}_{i,b}}$$

By definition, the sum of the on-base losses and the total in-flight losses equals the total losses, i.e.,

$$LB_{i,b} + LF_{i,b} = L_{i,b}$$

From the first assumption and the above definition we obtain:

$$LB_{i,b} = L_{i,b}\left(\frac{\overline{PKB}_{i,b}}{\overline{PKB}_{i,b} + \overline{PKF}_{i,b}}\right)$$

$$LF_{i,b} = L_{i,b}\left(\frac{\overline{PKF}_{i,b}}{\overline{PKB}_{i,b} + \overline{PKF}_{i,b}}\right)$$

Finally, from the second assumption and the preceding result for $LF_{i,b}$, we obtain:

$$\ell f_{i,b,n} = L_{i,b}\left(\frac{\overline{pkf}_{i,b,n}}{\overline{PKB}_{i,b} + \overline{PKF}_{i,b}}\right)$$

In the printed output the losses are shown by aircraft type rather than by the bases. Letting $L^*_{i,k}$ be the total losses among type-k aircraft, $LB^*_{i,k}$ the on-base losses among type-k aircraft, and $\ell f^*_{i,k,n}$ the in-flight losses on mission n for type-k aircraft, then*

$$L^*_{i,k} = \sum_{b \epsilon B_{i,k}} L_{i,b}$$

$$LB^*_{i,k} = \sum_{b \epsilon B_{i,k}} LB_{i,b}$$

$$\ell f^*_{i,k,n} = \sum_{b \epsilon B_{i,k}} \ell f_{i,b,n}$$

*These equations reflect our assumption that only a single type of aircraft is on each base.

Cumulative Summary

The TALLY player may obtain, at the beginning of the first cycle of each day, a cumulative summary of the results of game play up to that time. For each aircraft type and each mission type, this cumulative summary contains the expected number of sorties allocated, the expected number of sorties arriving at their targets, and the expected number of in-flight losses. It also shows the expected number of on-base losses for each aircraft type. The cumulative summary is displayed in the illustrative case in the annex to Appendix B.

MEASURES OF EFFECTIVENESS AND THE TALLY/TOTEM METHODOLOGY*

P. M. Dadant

The Rand Corporation, Santa Monica, California

If I were to say that a beauty contest is like a comparison of tactical war-fighting systems, you might disagree and say that it *is* a comparison of tactical war-fighting systems. I couldn't argue with that, but the analogy I would like to make is in terms of our subject for this session--"Measures of Effectiveness." Let me draw the analogy in three ways. First is the need for multiple criteria: the girl with the most beautiful eyes, for example, may not go far if her legs look like those of an All-American fullback. In like manner, the war-fighting system that produces the most enemy casualties, for example, may be judged poorly if it also produces the most friendly casualties. Second, intermediate measures don't tell very much of the story: a nice 26" waist doesn't mean much if you learn that the bust and hips are also 26. Likewise, a tactical fighter-bomber's high sortie rate means nothing if the sorties can carry no weapons. Thirdly, the final decision may boil down to a matter of taste. But to complete that analogy I need to develop some examples; and in order to do that I would like to get around to the principal task for which I was asked to give this paper, which was to explain some methodology we have developed at Rand for examining airpower in joint air-ground warfare.

For a recent study we wished to compare several different compositions and uses of airpower. Not being content with intermediate measures of the performances of the systems--the numbers of sorties the systems would produce, for example, or the numbers of munitions expended--we attempted to embed the airpower systems in an overall air-ground battle.

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*This paper was delivered, by invitation, to the Working Group on Measures of Effectiveness at the 31st meeting of the Military Operations Research Society in June, 1973.

CHART 1

For this we developed our TALLY/TOTEM methodology. Our model is actually two models that work closely together. Ground attack sorties from the air-battle model TALLY are fed into the ground-battle model TOTEM, and the movement of ground units from TOTEM may feed back into TALLY, where they may, for example, overrun airbases or force their evacuation. I want to make it clear at the outset that the purpose of our methodology was to compare different airpower systems and not to compare air systems with ground systems. We therefore accepted what you may consider to be some unevenness in aggregation between the two models as being adequate for our purposes. Now, you may argue that they are not satisfactory for even this limited purpose; my intent today is not to debate that question, but merely to explain the methodology, and then to demonstrate some things we may learn from it about measures of effectiveness.

Our overall methodology, incidentally, does consider the weather in the theater of operations, as I will explain later. This weather factor feeds into both the air and the ground models.

CHART 2

TALLY is a sort of conventional, circular air-battle model. One starts with the airfields of one side, generates sorties, runs these through an attrition computation that may vary with targeting, and applies the survivors to the targets. Then he repeats the process for the other side. It is at this point that the ground attack sorties are bled off to be fed into TOTEM. This completes one cycle; the whole procedure is then repeated for additional cycles. I will discuss the inputs in more detail, but I would like to mention that the model treats individual airbases and that one output is the aircraft surviving at each base at the end of each cycle.

CHART 3

TALLY is a two-sided expected-value model and we have two versions operating; one on an interactive computer system, JOSS, where the operator must allocate sorties to targets each cycle; the other, on an IBM

360/65, uses preprogrammed allocations. TALLY operates on 4 nominally 6-hour cycles per day, and the first cycle of a war being simulated may be a surprise-attack cycle, in which only one side is allowed to make attacks. It will handle 100 bases for each side, with both sheltered and unsheltered aircraft, and 20 aircraft types for each side.

CHART 4

For each cycle, the operator must allocate sorties to four missions: airbase attack (ABA); interdiction, which we called "mobility interdiction" (MI) because we used those sorties primarily against moving ground forces, and for which there are 3 types or "zones" allowed in order to simulate different penetration difficulties--that is, different attrition rates in getting to targets; close air support (CAS); and air defense (AD), which may be separated into defense over the battlefield or defense over airfields in the rear. He must also assign airbase attack aircraft, by type and by the number of aircraft, to individual target airbases; and he may move or augment aircraft each cycle. The outputs each cycle include the aircraft remaining at each base, aircraft losses broken down by the way in which they were lost, and the sorties surviving to deliver weapons in the ground-attack missions. These are the sorties that are then fed into TOTEM.

CHART 5

Several different inputs are required for aircraft, some of them dependent upon the mission for which the aircraft is to be used. Any of the inputs to TALLY, incidentally, can be changed at the beginning of any cycle to reflect changing conditions as the war progresses. For each aircraft type, TALLY requires inputs of the sortie rate, the sortie length, and the abort rate. For each air defense aircraft an airborne attrition rate must be input. For each aircraft to be used for airbase attacks, the program requires a beginning jettison rate and air-to-air attrition rate, a ground-to-air attrition rate, and several effectiveness numbers--against sheltered and unsheltered aircraft, and using either area-delivered or point-delivered weapons. The jettison

and air-to-air attrition rates are automatically adjusted each cycle to reflect changes in the numbers of enemy air-defense aircraft--through these aircraft being killed, augmented, or assigned to a different mission. The split of air defense aircraft between battlefield and rear-area defense may also be changed, of course, in which case the jettison and air-to-air attrition rates must be changed.

CHART 6

For close air support aircraft TALLY requires beginning jettison and air-to-air attrition rates, which are also automatically adjusted cycle by cycle, and several ground-to-air attrition rates. These ground-to-air attrition options are used to reflect different aircraft-type/delivery-tactic combinations. These, in turn, must correspond to the munitions being used and the various weather states being considered in the simulation, as I will touch on later, and must correlate with ground-attack effectiveness numbers used in TOTEM. Similar inputs are required for each interdiction type or zone.

TALLY also provides for one special aircraft type for each side. This may be used to simulate aircraft--bomber types, for example--that operate out of bases in sanctuary and that do no close air support. These aircraft may have distinctly different jettison and attrition rates in the interdiction mission, and may, as in one version of the program, be restricted to flying only at night.

CHART 7

I said before that TALLY deals with individual airbases, so it requires a number of inputs that characterize these bases. The aircraft type and inventory are required for each airbase, for example, as well as either a base vulnerability designation in the JOSS program--that is, whether the base has aircraft shelters or not--or in the IBM 360 program, the number of aircraft shelters at each base. The model also includes a disruption factor to reflect any decreased capability to mount sorties in the cycle after an airbase has been attacked. If there is a surprise attack, a special disruption factor may be applied to reflect the enhancement of the disruption due to being surprised.

The program computes the occupancy of each base at the time it is attacked. This is based on whether or not the attack is a surprise and whether it is night, when all aircraft are assumed to be on base, or day. If the attack is a surprise, some fraction of the aircraft on the base or some maximum number of aircraft may be assumed to be scrambled to get out from under the attack. If the attack is not a surprise and comes during daytime, the base occupancy is calculated as a function of the sortie rate, sortie length, and abort rate of the aircraft on the base, the number of daylight hours, and the disruption factor.

CHART 8

As I said earlier, consideration of weather is an integral part of the TALLY/TOTEM methodology. To integrate weather into the models, a number of geographical weather zones must be specified in the theater of operations--say, 10 or 20 zones. For each of these weather zones and for each cycle we specify the ceiling and visibility conditions. Each target or target area is then associated with a weather zone. For each air attack the weather determines the permissible flight profiles and delivery tactics, and the types of munitions that can be effectively delivered. Using these delivery profiles, we determine the aircraft ground-to-air attrition rates I mentioned previously, and by including the munitions delivered we get the effectiveness of each sortie in attacking ground targets.

CHART 9

The ground battle model, TOTEM, is quite different in structure. Here the ground forces of each side, the terrain, the objectives of each side, the engagement rules, and the ground attack sorties from TALLY are all folded into the simulation of the ground battle, from which comes the resulting status, casualties, and movement of forces.

CHART 10

TOTEM is also a two-sided, expected-value model operating on the same four cycles per day as TALLY. For ground-to-ground engagements,

TOTEM uses a single force-capability index. Although we have most often used an index based upon firepower scores, any index--personnel strength or whatever--may be used. TOTEM makes use of a geographic grid overlaid on the theater of operations, and ground forces are aggregated within each rectangle or "quad" of the grid. For many of our analyses we have used a 10 km x 10 km quad size so that the aggregation corresponds approximately to brigade or regiment level. The program relies primarily on tabular inputs for computing the casualties and movements experienced by the ground units. Among the outputs are the remaining strengths of ground units, their losses due to air attacks and due to ground-to-ground actions, and the positions of the units.

CHART 11

TOTEM allows 5 different terrain or trafficability categories, one of which must be specified for each quad in the grid. Unopposed movement rates depend only upon these trafficability conditions, and opposed movement rates depend on these conditions plus other factors. The model also allows several different action orders to be given to each ground unit: defend, attack, move, separate a part to contain a surrounded enemy unit, withdraw from an engagement, or split off units to take some other action. Six different postures are allowed for the defensive units, ranging from a hasty field defense to a heavily fortified position. An engagement is assumed to occur whenever opposing units are in the same quad, and the defense postures affect both sides' casualties due to ground-to-ground fighting and the movement rates of the engagements. The ratio of combat capabilities in each engagement also affect both its casualties and its movement each cycle.

CHART 12

One feature of TOTEM that I believe is unique is its treatment of ground attacks by airpower. In addition to the combat capability index for each unit, TOTEM carries separately the numbers of tanks, armored personnel carriers, artillery, and "other vehicles" in each unit. The air sorties from TALLY are used to attack these four classes of vehicles, employing munitions and delivery tactics compatible with the

weather and using a sortie effectiveness that is input for each aircraft-type/munitions-type/delivery-tactic combination against each type vehicle in each of 3 different exposure postures. The sorties attacking a given ground unit are divided among vehicle types in proportion to the numbers carried for each type in that unit; a given vehicle type can be discriminated against in these attacks by carrying only some fraction of those actually present. The vehicles killed by these air attacks are converted into their index equivalents and these are subtracted from the capability indexes of the units.

TOTEM incorporates an automatic feature for distributing close air support sorties among the engaged enemy units to be attacked. This feature normalizes sorties and apportions them in proportion to the capability indexes of the enemy units and in proportion to the ratios of enemy capability to friendly capability in these engagements--apparently a good way of assigning sorties, but not necessarily optimum. This feature can be overridden by manual inputs whenever desired. The effectiveness of the sorties is also adjusted as the war progresses to reflect an increasing difficulty both in finding vehicle targets and in discriminating against dead vehicles.

You notice from this, of course, that air is treated somewhat differently from ground in this methodology. It is for that reason that one should be wary in applying the methodology to comparisons for which it was not intended.

CHART 13

The outputs from TOTEM are many and varied, and we needn't go into them now except to say that at the end of each cycle several outputs are available for each engagement, for each unit of force, and for some aggregations both for that cycle and for the game to date.

Let me turn now to what we can learn about measures of effectiveness by using this TALLY/TOTEM methodology. I will do this by comparing the results that we have obtained from some cases that we have run through this model. The scenario is actually immaterial for my purposes today, but let me just say that it is a not unrealistic scenario of an attack by Warsaw Pact forces against NATO forces in Central Europe.

All of the starting conditions for the first two cases I'll show, the way that the battle develops, and all augmentation forces are exactly the same. The difference in the two is in the way that airpower is used.

CHART 14

I show here four measures of effectiveness for the two cases, two for airpower on the left hand chart and two for the ground situation on the right hand chart. But let's consider them one at a time. First, let me say with regard to the air parameters that Pact airpower results were so similar in the two cases that I have not shown them here, but show only the results for NATO airpower. Looking first at surviving NATO aircraft, we see that Case B has resulted in a substantially greater number of aircraft surviving at the end of 7 days than has Case A. At the same time, however, Case B has resulted in substantially fewer close air support sorties being flown in support of the ground battle. Looking at the right hand chart we see that the extra sorties of Case A have reduced the Pact-to-NATO combat ratio on the ground and that the ground advance by Pact forces has been held back more successfully by Case A. Case B, in fact, has resulted in nearly a 30 percent greater loss in NATO defended territory. Three of these measures of effectiveness, then, seem to say that Case A is better, and if we could be sure that the war would stop at the end of 7 days we might prefer Case A. But let's look further.

CHART 15

Notice that I have compressed the time scale on these charts, but that the first 7 days repeats what you saw on the former charts. Looking again at aircraft, at the end now of 15 days, we see again that Case B has the greater number of surviving aircraft. By this time, however, this larger number of aircraft has produced a larger number of close air support sorties. On the right hand chart we see that this has resulted in a decrease in the ground combat ratio until that ratio in Case B is now better for NATO than it is in Case A. However, NATO has still lost some 20 percent more territory in Case B than in Case A.

By the end of 15 days, then, we see that two of our measures of effectiveness have crossed over so that Case B seems to be preferred to Case A, and we now have three measures in which Case B looks better and only one where it looks worse. Now notice that what I would call an intermediate measure, the number of close air support sorties flown, favors Case B by about 20 percent, but that this intermediate measure doesn't really tell us much about the full story. Neither, of course, does any one measure, and we need to look at a number of the measures of effectiveness in order to make a good comparison. At the same time, a preference decision may depend upon still other factors. For example, has the Pact force reached its objectives by the end of 15 days so that NATO reinforcements on Day 16 would be too late? Would those same reinforcements in Case A halt the Pact force short of its objectives? Or is it a matter of taste whether the added territory lost in Case B is a reasonable trade-off for the increased number of surviving aircraft in that case? But let's pursue the cases for a few more days, in this instance without more NATO reinforcements.

CHART 16

Here we see that Case B continues to build up a superiority in close air support sorties and that these have resulted in slowing down the Pact advance until, on about Day 22, the defended area lost in the two cases crosses over. Now Case B appears to be preferred on all four measures. But perhaps it's a matter of taste. At least it may be a matter of taste just prior to that cross-over in area lost. Suppose, for example, that an end to the war had been negotiated on Day 20, or that NATO reserves could reach the area and halt the advance on Day 20. In any case, at this point the difference in area lost is only 5 percent. Is that a good trade for the extra 40 percent surviving NATO aircraft that can be used, perhaps, to meet some other contingency? Of course, we don't believe the results of models like this in any such fine-grained detail; I use it here only to illustrate a point: these trade-offs of aircraft--or ground forces--for area do exist, and choices may depend upon judgment or "taste".

In these two cases the extra aircraft surviving in Case B are finally able to turn the battle around on the ground in comparison to Case A. If you think the surviving aircraft is a good enough measure, however, and we needn't look at the others, let me show you a comparison of two other cases.

CHART 17

In these cases, again, all of the starting forces and augmenting forces are the same, and again the battle develops in the same fashion. But NATO aircraft are again used differently in the two cases, and in Case C the NATO aircraft have been attrited at a much higher rate so that nearly three times as many aircraft survive at the end of 21 days in Case D as in Case C. So, is Case D preferred? The higher attrition in Case C has actually been suffered because of the way the aircraft have been used and, although they have suffered more attrition, they have also been more effective. By the end of 21 days the larger number of survivors in Case D is resulting in a larger number of close air support sorties being flown, however, and one might expect that, as in the previous comparison, the ground battle would eventually be slowed down and we would find a cross-over in area lost. What has actually happened we can see on the right hand graph. In Case C the combat ratio has been driven so low by the end of 21 days that the ground battle has come to a standstill. Although Case D may eventually also reach a standstill, it will be at a point with about twice the defended area lost. Now which case do we prefer?

These two cases illustrate a couple of things. One I have already hinted at, and that is yet another measure of effectiveness, which is either the time taken to reach given objectives on the ground--say, the time for Pact forces to reach the Rhine, for example--or the time until the front is stabilized, if that happens. In some cases this "time" may be the single most meaningful measure; in most, however, it is probably useful only in conjuction with other measures.

The other thing illustrated I have already mentioned explicitly, and that is the trade of area on the ground for remaining war-fighting

capability. In these two cases we see that the one that has lost the more area, Case D, also has the larger number of aircraft remaining. These aircraft, of course, may constitute a valuable resource if another contingency should break out somewhere else at about this time. The preference decision, then, may really boil down to a matter of taste.

In order to make a choice among cases, or among forces and their employments, it is clear that we must use *all* of these measures, and perhaps several others as well. I suggest, therefore, that in our work relating to force effectiveness we must be sure that we have an adequate *menu* of MOEs. And even then we must recognize that in many cases these measures will be so disparate that easy tradeoffs or decisions cannot be expected.

TALLY/TOTEM METHODOLOGY

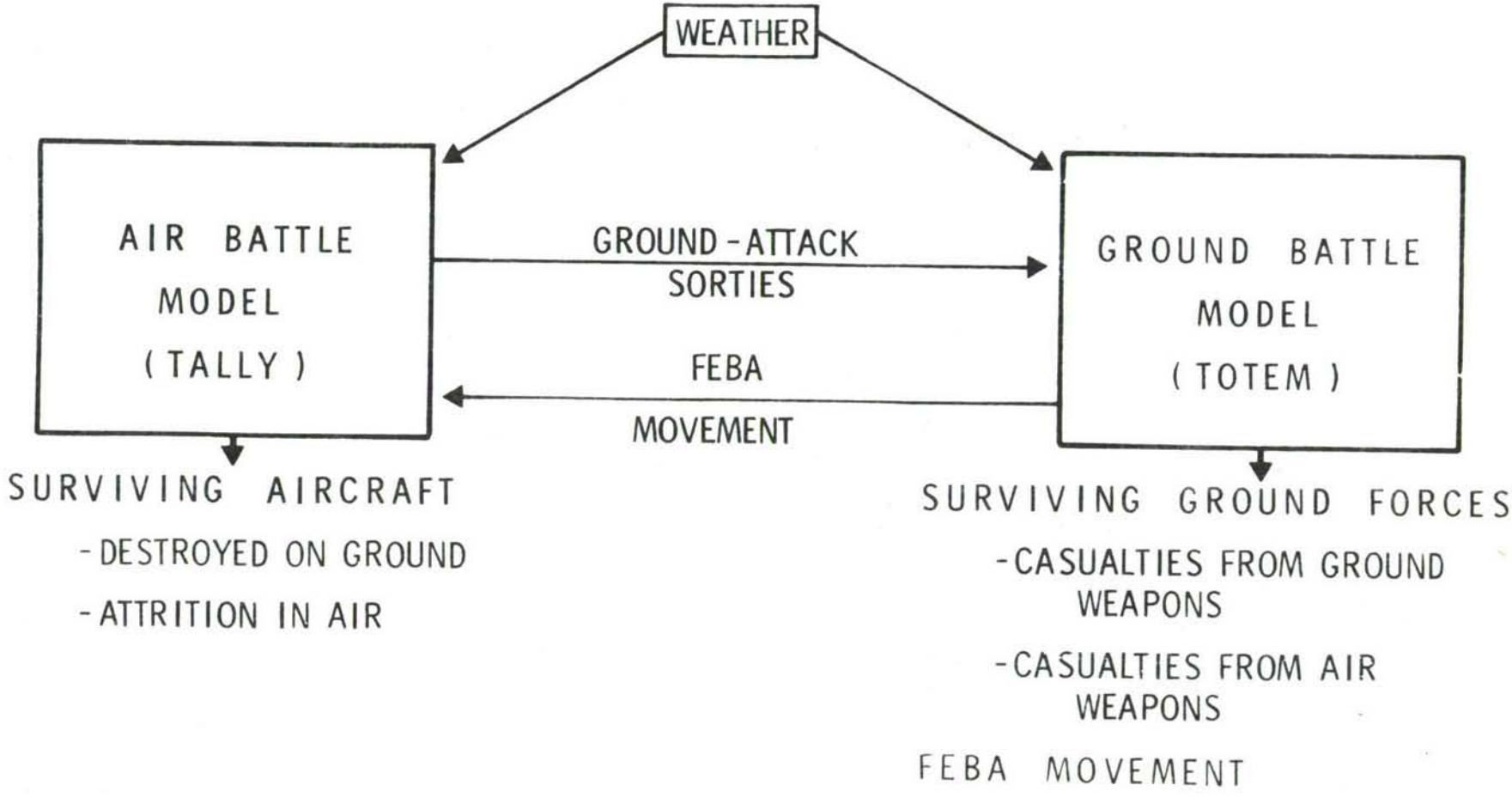
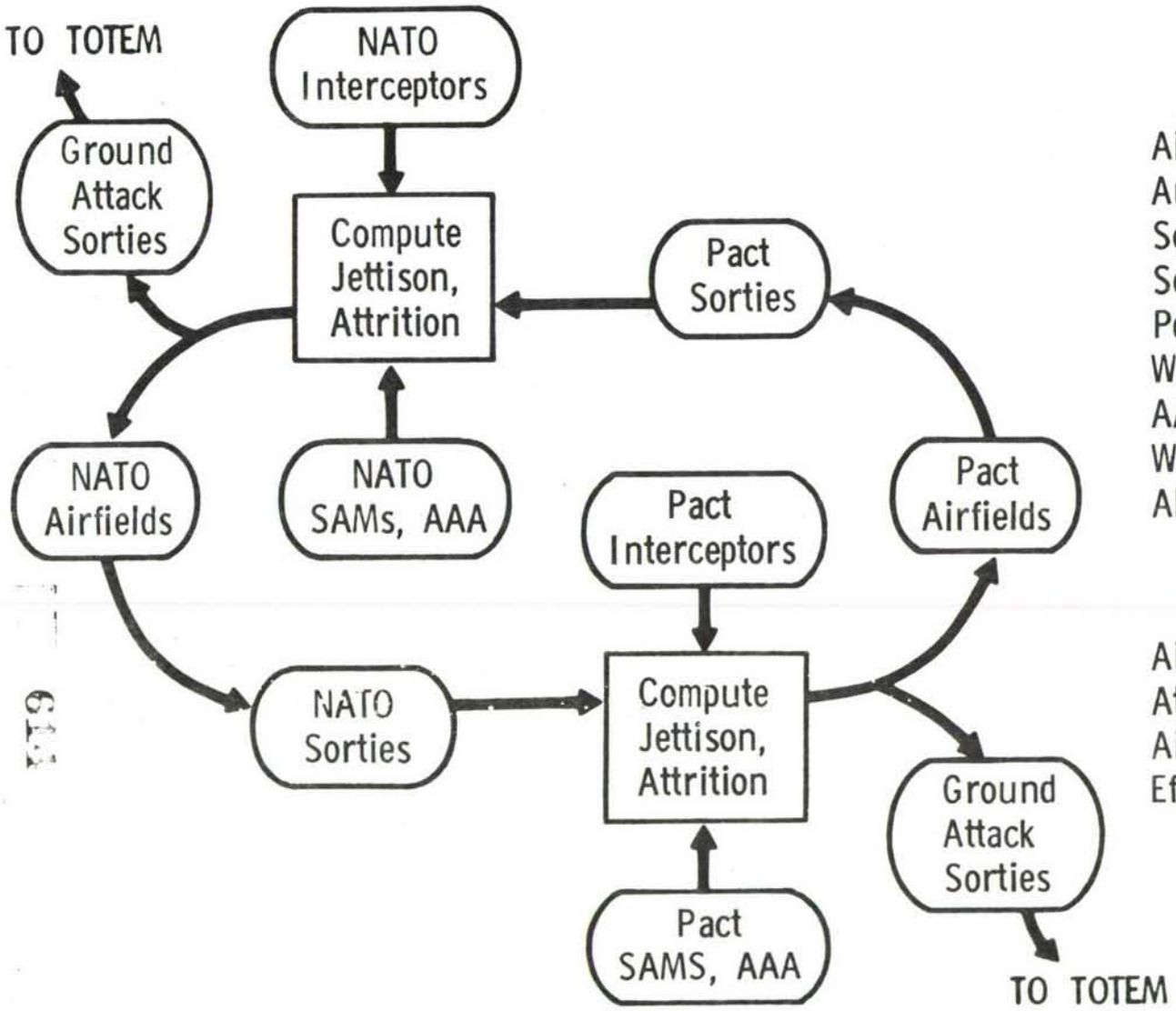


CHART 1

AIR BATTLE MODEL
(TALLY)



INPUTS

Aircraft & Bases
Augmentation Schedule
Sortie, Abort Rates
Sortie Lengths
Pd, Pc, Pj, Pk
Weapon Effects
AAA & SAM Effects
Weather
Allocation

OUTPUTS

Aircraft Killed on Ground
Attrition in Air
Aircraft Remaining Each Base
Effective Ground Attack Sorties
(To Totem)

CHART 2

TALLY: GENERAL DESCRIPTION

- TWO-SIDED EXPECTED-VALUE MODEL
- TWO VERSIONS
  - JOSS: INTERACTIVE AIR ALLOCATIONS
  - IBM 360/65: PREPROGRAMMED ALLOCATIONS; ITERATE
- FOUR CYCLES PER DAY
  - 1 & 4, NIGHT; 2 & 3, DAY
  - BEGINNING CYCLE MAY BE SURPRISE ATTACK
- 100 BASES EACH SIDE
  - SHELTERED AND UNSHELTERED AIRCRAFT
- 20 AIRCRAFT TYPES EACH SIDE

TALLY: GENERAL DESCRIPTION (Cont.)

- OPERATIONS
  - ALLOCATE SORTIES TO
    - Airbase Attack (ABA)
    - Interdiction (MI)
      - 3 "zones" or types
    - Close Air Support (CAS)
    - Air Defense (AD)
      - Over battlefield or over airfields
  - ASSIGN ABA AIRCRAFT TO TARGET AIRBASES
  - MOVE, AUGMENT AIRCRAFT
- OUTPUTS
  - REMAINING INVENTORY EACH BASE
  - LOSSES ON GROUND, IN AIR
  - SORTIES DELIVERING WEAPONS IN MI, CAS

To TOTEM

CHART 4

TALLY: AIRCRAFT INPUTS

- EACH AIRCRAFT TYPE
  - SORTIE RATE
  - SORTIE LENGTH
  - ABORT RATE
- AIR DEFENSE AIRCRAFT
  - AIRBORNE ATTRITION RATE
- EACH ATTACK AIRCRAFT TYPE

  ABA: Beginning Jettison Rate
  Beginning Air-Air Attrition Rate
  Ground-Air Attrition
  PK in ABA:
  - vs. sheltered and unsheltered aircraft
  - using area or point weapons

TALLY: AIRCRAFT INPUTS (Cont.)

- CAS AIRCRAFT
  - BEGINNING JETTISON RATE
  - BEGINNING AIR-AIR ATTRITION RATE
  - GROUND-AIR ATTRITION RATE
    - 9 Options for aircraft types/delivery tactics
- MI AIRCRAFT, EACH MI "ZONE"
  - BEGINNING JETTISON RATE
  - BEGINNING AIR-AIR ATTRITION RATE
  - GROUND-AIR ATTRITION RATE
- SPECIAL AIRCRAFT TYPE
  - BASES IN SANCTUARY
  - NO CAS
  - DISTINCT JETTISON AND ATTRITION RATES IN MI
  - BLUE: FLY ONLY AT NIGHT

CHART 6

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TALLY: AIRBASE INPUTS AND OCCUPANCY

- EACH BASE
  - AIRCRAFT TYPE
  - AIRCRAFT INVENTORY
  - BASE VULNERABILITY TYPE (JOSS)
  - NUMBER SHELTERS (360)
- DISRUPTION FACTOR FOR ATTACKED BASES
  - SPECIAL FACTOR FOR SURPRISE ATTACK
- BASE OCCUPANCY WHEN ATTACKED
  - SURPRISE ATTACK: Max. scrambled (% or no. of aircraft)
  - NIGHT: All aircraft on base
  - DAY: Function of sortie rate, sortie length, number of daylight hours, abort rate, and disruption

CHART 7

623

WEATHER FOR TALLY/TOTEM

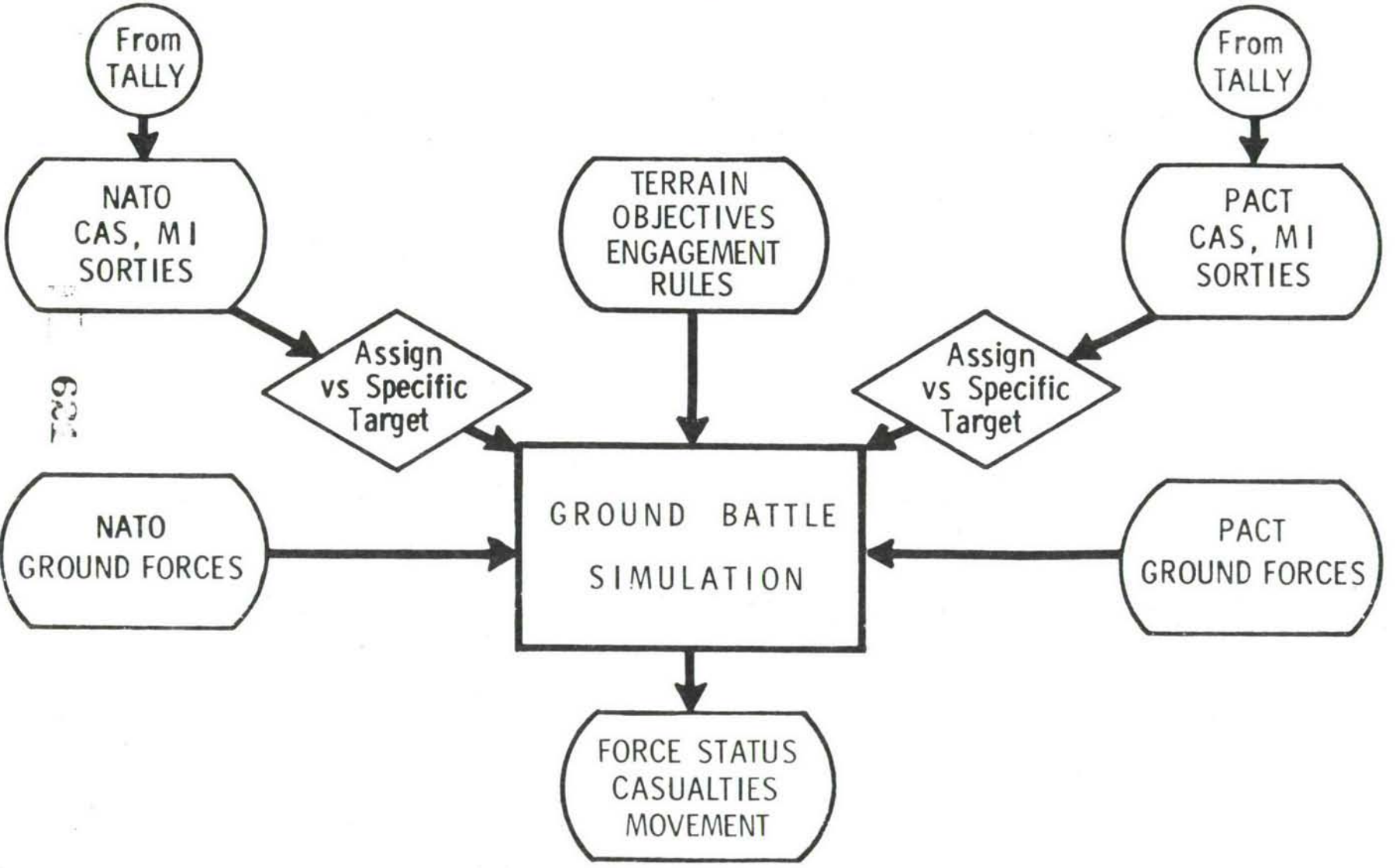
- GEOGRAPHICAL WEATHER ZONES SPECIFIED
- FOR EACH ZONE, EACH CYCLE, SPECIFY
  - CEILING
  - VISIBILITY
- AIRBASE, MI, CAS TARGETS LOCATED IN WX ZONES
- WEATHER DETERMINES, FOR EACH MISSION
  - PERMISSIBLE FLIGHT PROFILES
  - PERMISSIBLE DELIVERY TACTICS
  - WEAPON TYPES EFFECTIVE

THEREFORE:

- AIRCRAFT ATTRITION
- AIRCRAFT SORTIE EFFECTIVENESS

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GROUND BATTLE MODEL
(TOTEM)



TOTEM: GENERAL DESCRIPTION

- TWO-SIDED EXPECTED-VALUE MODEL
- FOUR CYCLES PER DAY
  - 1 & 4, NIGHT; 2 & 3, DAY
- USES FORCE CAPABILITY INDEX FOR GROUND-GROUND BATTLE
- EMPLOYS GEOGRAPHIC GRID
- PRIMARILY TABULAR INPUTS FOR
  - CASUALTIES
  - MOVEMENTS
- OUTPUTS
  - REMAINING GROUND FORCES
  - LOSSES DUE TO AIR, GROUND ATTACKS
  - POSITIONS OF FORCES

CHART 10

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TOTEM: (SOME SPECIFICS)

- 5 TERRAIN / TRAFFICABILITY CATEGORIES
  - UNOPPOSED MOVEMENT RATE EACH SIDE, EACH CATEGORY
- UNIT ACTION ORDERS
  - DEFEND
  - ATTACK — IN GIVEN DIRECTION; TOWARD STATED OBJECTIVE
  - MOVE (AND JOIN) — TO GIVEN LOCATION (GIVEN UNIT)
  - CONTAIN (BY SEPARATING FORCE) AND ATTACK
  - WITHDRAW FROM ENGAGEMENT — TO GIVEN LOCATION
  - SPLIT OFF UNITS — TO TAKE DESIGNATED ACTIONS
- DEFENSE POSTURES
  - HASTY FIELD DEFENSE
  - DELIBERATE DEFENSE
  - PREPARED POSITIONS (3 LEVELS)
  - FORTIFIED POSITION

TOTEM: GROUND ATTACK BY AIR

- FOR EACH UNIT, TOTEM TABULATES:
  - TANKS
  - APCs
  - ARTILLERY
  - OTHER VEHICLES

- AIR SORTIES ATTACK VEHICLES
  - KILL VEHICLES
  - DELAY MOVING COLUMNS

- FOR KILLED VEHICLES, INDEX EQUIVALENT SUBTRACTED

CHART 12

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TOTEM: OUTPUTS EACH CYCLE

FOR EACH ENGAGEMENT

- POSITION
- TYPE
- UNIT IDENTITIES
- UNIT VALUES (Initial)
- CASUALTIES
  - Due to Air
  - Due to Ground
- UNIT VALUES (Final)
- MOVEMENT
- NORMALIZED AIR SORTIES

FOR EACH FORCE UNIT (Blue and Red)

- POSITION
- VALUE
- TANKS
- APCs
- ARTILLERY
- VEHICLES
- ACTION
- CONTACT
- ENGAGEMENT TYPE
- CASUALTIES

FOR THIS CYCLE AND FOR GAME TO DATE (Blue and Red)

- AIR SORTIES
- NORMALIZED AIR SORTIES
- $\leq$ (UNIT MOVEMENTS)
- CASUALTIES
  - Due to Air
  - Due to Ground
  - Total
- ENGAGED VALUES
- REMAINING VALUES

HISTORY OF 4 MOEs FOR CASES A AND B

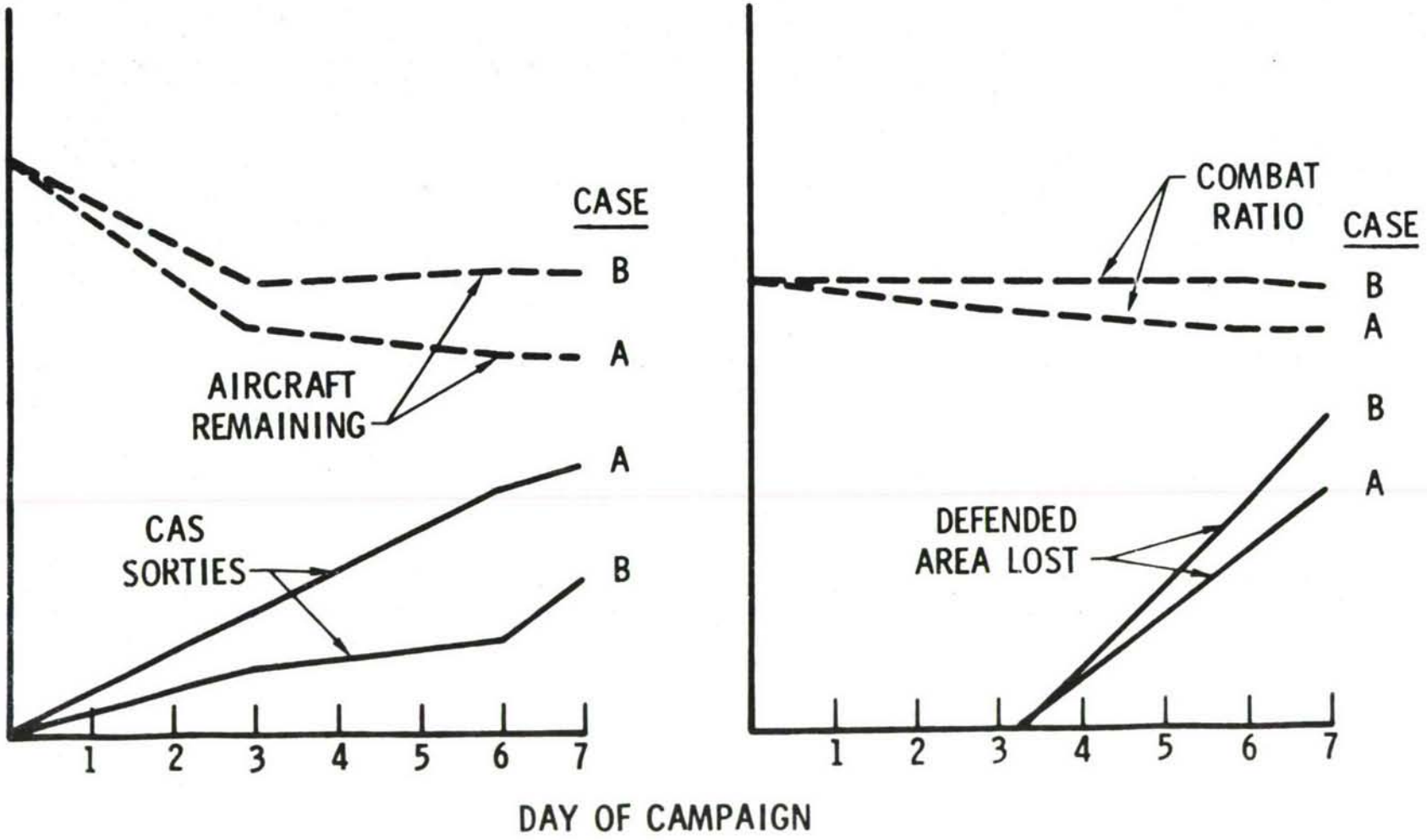


CHART 14

HISTORY OF 4 MOEs FOR CASES A AND B

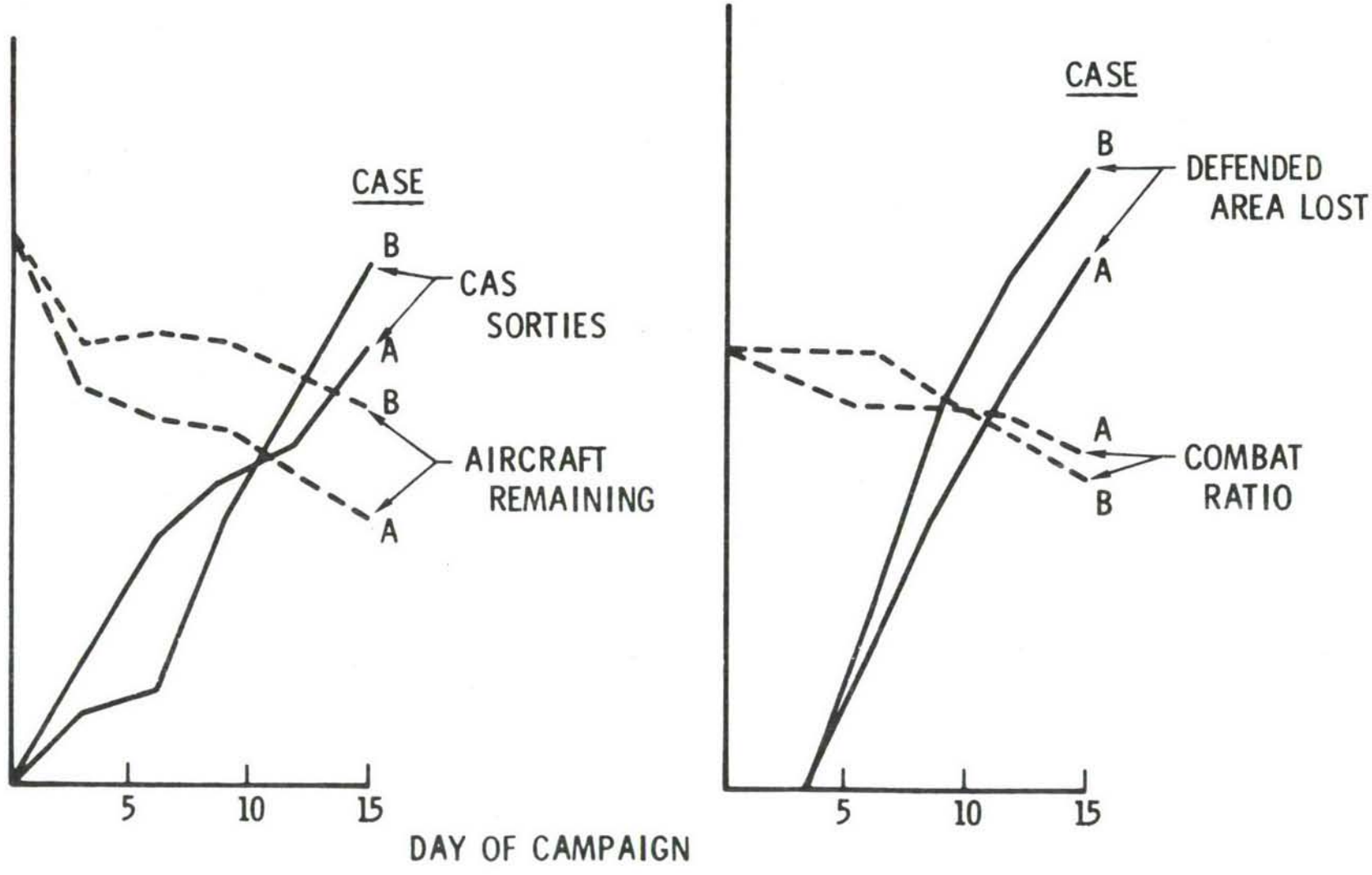
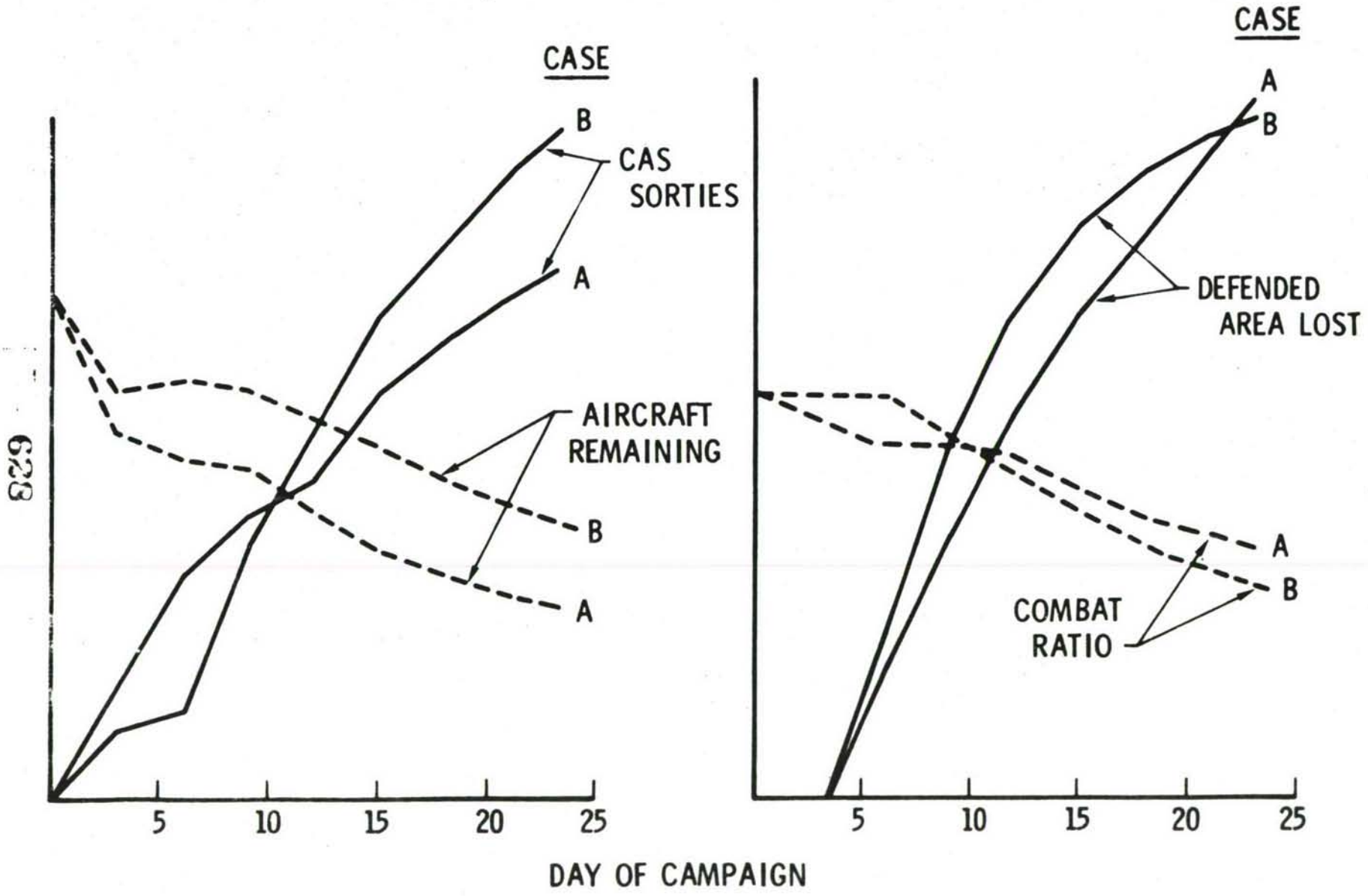


CHART 15

HISTORY OF 4 MOEs FOR CASES A AND B

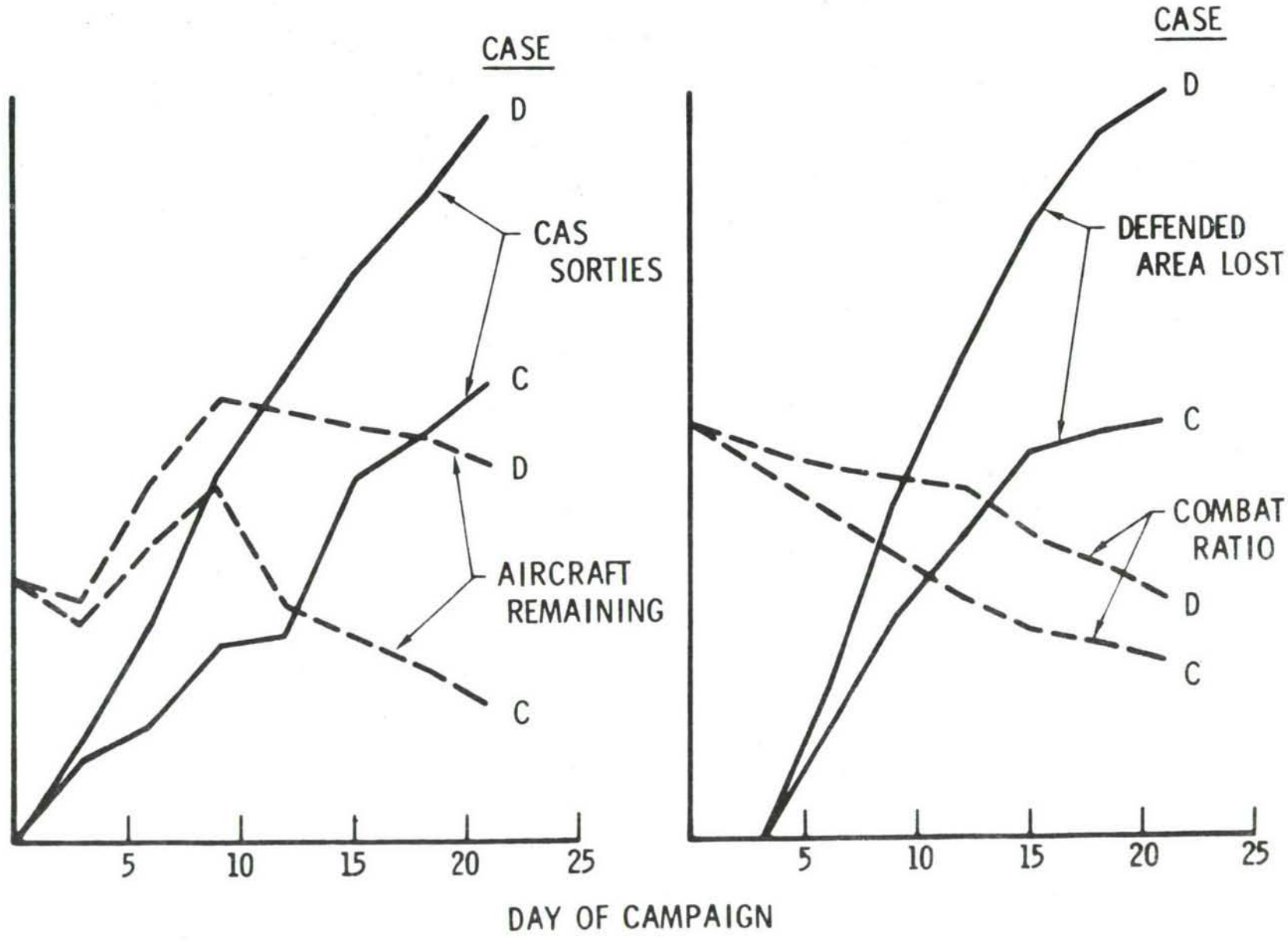


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-27-

CHART 16

HISTORY OF 4 MOEs FOR CASES C AND D



JOINT THEATER-COMBAT MODEL COMPARISON AND EVALUATION STUDY

(Concept and Objectives)

Prepared by: Dr. F. B. Kapper

D R A F T

27 February 1975

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D R A F T

JOINT THEATER-COMBAT MODEL COMPARISON AND EVALUATION STUDY

(Concept and Objectives)

1. Study Concept:

a. The basic idea is to conduct a joint study of three computerized models: IDAGAM-I, LULEJIAN-I, and VECTOR-I. The assumptions, characteristics and capabilities of each model will be compared with those of the other two. The three models will be evaluated relative to their ability to portray and analyze selected aspects of theater combat.

b. The study is to be performed under the general direction of a Steering Committee composed of participating Agency Heads, and chaired by the Director, WSEG. The Study Manager will be provided by WSEG, and the Study Team members will be drawn from the resources of participating agencies. The study's progress will be monitored on a routine basis by a Review Group composed of one representative from each participating agency. The Review Group will also provide other specific guidance as required.

c. The study is to be divided into two distinct segments. The first part will focus on a definition of criteria and a "paper" comparison of the three models using all available documentation. This segment of the study is to be for a duration of three months. The second part is to last six months. It will consist of controlled testing of and experimentation with all three theater-combat models. The complete study is to be performed in a nine-month period. It is to officially begin on 1 May 1975 and conclude on 30 January 1976. It is estimated that approximately 50 man-months will be required for its successful completion.

d. The Study Manager is responsible for producing two joint reports -- one for each segment of the study. The reports are to be due at the end of each study segment. They will document the bases for as well as the results of all model comparisons and evaluations made during the study. Each report is to be reviewed for technical and editorial correctness by the Review Group and, thence, forwarded to the Steering Committee for approval as appropriate.

2. Goal: To compare and evaluate scientifically the assumptions, characteristics, and capabilities of three models of a similar nature: IDAGAM-I, LULEJIAN-I, and VECTOR-I.

3. Corollary Goals and Specific Planning Objectives:

A. Initation Tasks

1. Develop by 1 March 1975 an agreed study concept and objectives document.

2. Establish by 8 March 1975 a "joint" organizational entity with the necessary responsibility and authority for the successful implementation of the study concept, objectives, and action plan.

3. Prepare by 8 March 1975 an agreed tasking statement for overall study implementation by WSEG.

4. Develop by 27 March 1975 an agreed general action plan for the first segment of the study to scientifically compare and evaluate the IDAGRAM-I, LULEJIAN-I, and VECTOR-I models.

5. Develop by 4 April 1975 an agreed assignment of specific task responsibilities, according to Agency interest and capability, and the needs of the study effort.

B. Part I - (Analysis of Model Documentation)

1. Create by 18 April 1975 an agreed time-phased schedule to implement the study concept via the action plan for Part 1 of the study.

2. Establish by 18 April 1975 an agreed tracking and reporting procedure for monitoring study activities and milestones.

3. For the cross-model comparison/evaluation develop or establish by 16 May 1975 agreed general measures of merit and evaluation criteria (criteria of judgment), identifying those which must be derived as appropriate.

4. Conduct, between 1 May and 31 July 1975, the first segment (Part 1) of the study proper, performing those reviews and analyses to identify the relative value of each model to portray and analyze selected aspects of theater combat.

5. Uniformly document by 31 July 1975, each model's assumptions, characteristics, and capabilities as well as the results of all comparisons and evaluations performed during the first segment of the study. Recommendations concerning each model's potential and cost for further development may also be included.

C. Part II - (Controlled Testing and Experimentation)

1. Develop by 20 June 1975 an agreed general action plan for the second segment (Part 2) of the study to scientifically compare and evaluate the IDAGAM-I, LULEJIAN-I, and VECTOR-I models. This portion of the study is to emphasize the controlled testing of and experimentation with all three models.

2. Develop by 27 June 1975 an agreed assignment of specific task responsibilities, according to Agency interest and capability, and the needs of the study effort.

3. Create by 11 July 1975 an agreed time-phased schedule to implement the study concept via the action plan for Part 2 of the study.

4. Establish by 11 July 1975 an agreed tracking and reporting procedure for monitoring study activities and milestones.

5. For the cross-model comparison/evaluation develop or establish by 18 July 1975 agreed general measures of merit and evaluation criteria (criteria of judgment), identifying those which must be derived as appropriate.

6. Conduct, between 1 August 1975 and 31 January 1976, the second segment (Part 2) of the study proper. Perform tests, experiments and analyses to identify the relative value of each model to portray and analyze selected aspects of theater combat.

7. Uniformly document by 31 January 1976 each model's assumptions, characteristics, and capabilities as well as the results of all comparisons and evaluations performed during the second segment of the study. Recommendations concerning each model's potential and cost for further development may also be included.

4. Action Plan (Outline):

a. A draft action plan was jointly developed in December 1974, and further refined in January into early February 1975. This plan tentatively identifies ten major phases for the total nine-month study. Each study segment is composed of five phases.

b. The first segment (Part 1) of the overall study is mainly oriented to an analysis of available model documentation. Its initial phase involves clearly defining the "paper analysis" problem and identifying the factors important to its solution. Other key tasks in this phase are to establish and finalize terms of reference and to create appropriate model checklists and questionnaires. The second phase involves acquiring all available documentation and general model familiarization, an examination of model characteristics, related data gathering, and finalization of the evaluation procedures. The actual comparison of model assumptions, characteristics, and capabilities as determined principally by study and analysis of available documentation constitutes the third phase. The fourth phase is to be a further analysis and evaluation of the findings of phase three. Each model's documented assumptions, characteristics and capabilities are to be evaluated as to their impact upon each model's relative ability to portray/analyze selected aspects of theater combat. Evaluation is to be performed in line

with appropriate measures of merit and standards of excellence. The fifth and final phase of the first study segment is largely devoted to documentation of results and conclusions.

c. The second segment (Part 2) of the study begins with the clear specification of test and experimental objectives, procedures and designs. These are necessary to ensure controlled and repeatable tests and experiments. The actual tests and experimentation makeup phase two. The third phase is devoted to a comparison of results. All comparisons are to be primarily based upon the experimental and test designs and parameters developed/identified in phase one. The next phase involves an analysis and evaluation of the results and comparisons of the preceeding phase consonant with appropriate measures of merit and standards of excellence. The last phase is for documentation of the results, analyses, evaluations, and conclusions of the second study segment (Part 2).

d. It is anticipated that some overlap in the time-sequencing of the various phases will occur. The overall plan is briefly outlined below:

5. Action Plan Summary

ACTION PLAN OUTLINE (TENTATIVE)

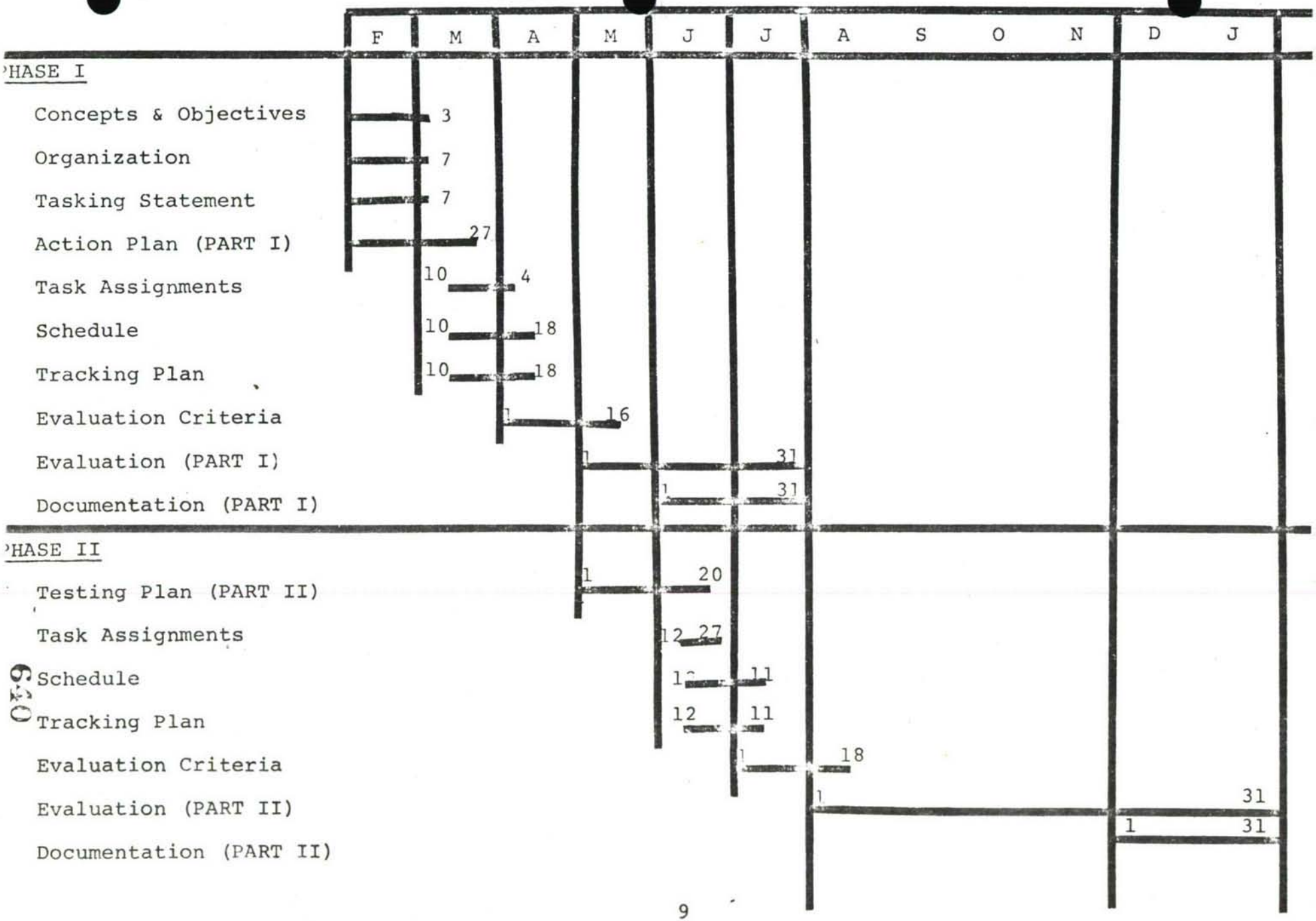
Part 1 of the Complete Study (Analysis of Model Documentation)

Phase	Major Activity
I	Problem Definition
II	Model Familiarization
III	Model Comparison
IV	Analysis & Evaluation
V	Document Results & Conclusions

Part 2 of the Complete Study (Controlled Testing & Experimentation

Phase	Major Activity
I	Formalize Specific Test & Experimentation Objectives, Procedures and Designs
II	Conduct Tests & Experiments
III	Comparison of Test & Experimental Results
IV	Analysis & Evaluation
V	Document Results, Analyses, Evaluations and Conclusions

ACTION PLAN SCHEDULE (TENTATIVE)



TECHNICAL SUPPORT DIVISION
STUDIES, ANALYSIS, AND GAMING AGENCY

ORGANIZATION OF THE JOINT CHIEFS OF STAFF
Washington, D.C. 20301

18 January 1974

IDAGAM I

ACQUISITION AND IMPLEMENTATION PLAN

IDAGAM I

ACQUISITION AND IMPLEMENTATION PLAN

18 January 1974

Prepared By:

W. Eckhardt and LTC H. J. Walther, USA
Technical Support Division

Reviewed By:

Francis B. Kapper

FRANCIS B. KAPPER
Scientific and Technical Advisor
Studies, Analysis, and Gaming Agency

Recommended for Approval:

W. E. Hutchison

W. E. HUTCHISON
Colonel, USMC
Chief, General Purpose Forces Division

Approved By:

H. A. Strack

H. A. STRACK
Brigadier General, USAF
Chief, Studies, Analysis, and Gaming Agency

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FOREWORD

This plan, prepared by the Technical Support Division, Studies, Analysis, and Gaming Agency (TSD/SAGA) of the Organization of the Joint Chiefs of Staff (OJCS) specifies the tasks, schedules, and responsibilities required to acquire and test the simulation model IDAGAM I for implementation by SAGA in support of the current Air Battle Study (ABS).

This plan is intended to be a paradigm plan for all future model acquisition activities of SAGA.

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ACQUISITION AND IMPLEMENTATION PLAN: IDAGAM I

1. INTRODUCTION:

a. This document is organized into five (5) main sections, covering general introduction, concept of operations, specific objectives, responsibilities, and schedules. Identified are the specific activities to be completed, as well as the general procedures to be followed in achieving a satisfactory version of the IDAGAM model for operational use by the General Purpose Forces Division (GPFD) of Studies, Analysis, and Gaming Agency (SAGA).

b. The plan also identifies an organization for model acquisition and implementation, a methodological approach for model testing and data base acquisition, desired milestones, and differentiated responsibilities. The acquisition process includes modifications for on-line operation and improvements to input and output, as well as conversion for use on the NMCSSC IBM and HIS computers.

c. This plan has been purposely designed to expedite the acquisition of IDAGAM I by SAGA for use in the SECDEF-directed Air Battle Study (ABS). The application of IDAGAM I to the ABS by 1 April 1974 is a firm requirement.

2. CONCEPT:

a. The IDAGAM I model is composed of five basic modules: Input, Air Combat (AC), Ground Combat (GC), Theater Control (TC),

and Output. Based on recommendations from SAGA, IDA will modify the input and output modules to improve analyst usability and satisfy certain SAGA requirements not presently included. As modules are completed, IDA will test (using test data) in a progressive and comprehensive manner. This testing will begin with the model's components, proceed to its subroutines, ultimately testing the model as a complete entity.

b. The NMCSSC will accomplish conversion of the programming from CDC to IBM as each module passes the initial IDA test. NMCSSC will also verify that all converted modules produce identical results to the earlier/original CDC-coded modules. Subsequently, an RJE/RLP capability will be added to the model by NMCSSC and the entire model converted, and results verified for use on the HIS.

c. Concurrent with the above actions, IDA with SAGA assistance, will develop a complete Base Case Data Base. This data base will be used to run the entire model on the IDA CDC computer. The results therefrom will constitute the bench mark for testing and verifying the results of IBM and HIS conversions of the model.

d. In order to initiate the Air Battle Study in a timely manner, initial IDAGAM runs will utilize the IBM version. However, since the ABS will continue beyond 30 June 1974, the

conversion to HIS must be accomplished NLT that date since the availability of IBM 360/67 computer time beyond 30 June 1974 is questionable.

3. OBJECTIVES:

a. The principal goal of this effort is to provide a model to the GPFD/SAGA which can be successfully used to support the requirements of the ABS. The basic theory of IDAGAM I appears to meet the stated ABS requirements. IDAGAM I is to be tested by IDA. This test must be comprehensive, progressive, and achieve the following objectives:

(1) Verify that all mathematical and logical algorithms are correctly programmed.

(2) Verify the stated range of values permitted for each input variable.

(3) Verify that bookkeeping for each accountable entity is correct.

(4) Verify that all input data are read and stored properly.

(5) Verify that all output data are obtained from the appropriate location(s) and formatted and printed correctly.

(6) Determine the military soundness of all combat interactions represented.

(7) Determine the sensitivity of critical output variables to variations of input data.

(8) Verify the consistency of treatment of all combat interactions represented.

b. The base case data assembly and operational testing are designed to achieve the following objectives:

(1) Determine the availability of the required data.

(2) Assessment of the capability of the model to satisfy ABS requirements.

(3) Train GPFD/SAGA user personnel.

c. Although it is not absolutely essential to the ABS, a highly desirable feature and ultimate objective is to include in the finalized version of the input and output modules, the capability to accomplish the following tasks from remote terminals in GPFD:

(1) Input of all required data.

(2) Initiation of batch runs for execution of a simulated theater campaign.

(3) Review portions of the output file.

(4) Execute printing of all or portions of the output file on the GPFD remote line printer.

4. RESPONSIBILITIES:

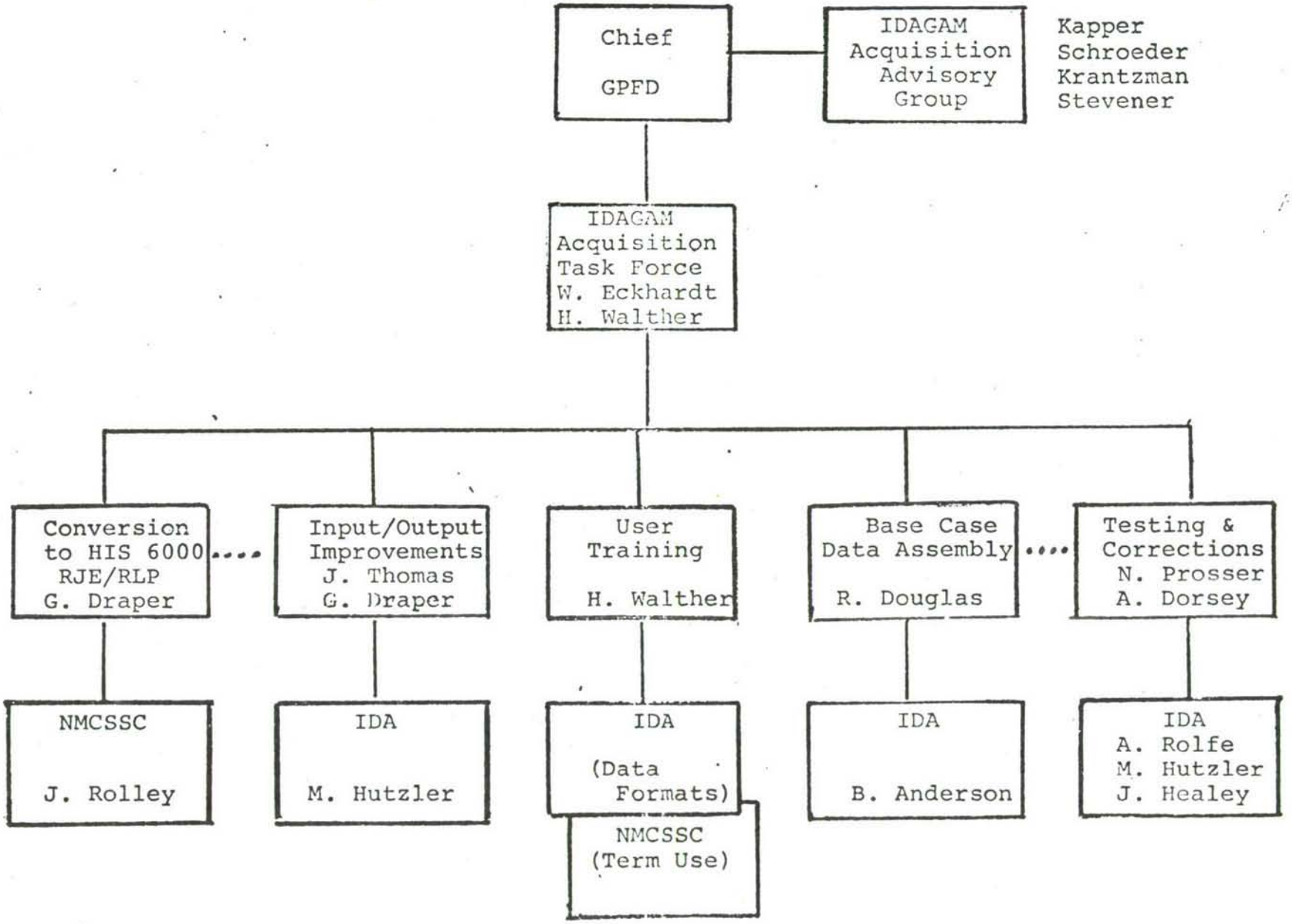
a. A list of over 50 tasks (not meant to be all inclusive) highlights the sequence of events necessary to accomplish the four major efforts involving data development, training, testing, and implementation in acquiring and implementing IDAGAM for the

ABS. Since these tasks involve personnel from SAGA, NMCSSC, IDA, and WSEG, an ad hoc organization (see Figure 1) will control and coordinate the acquisition of IDAGAM I. The organization depicted in Figure 1 is not intended to alter existing organizational structures, but does identify those personnel responsible for specific activities, and with whom each type of activity should be coordinated.

b. As noted, four major functional efforts characterize the acquisition and implementation of IDAGAM I. Figure 2 depicts these four efforts and the major elements of each. These functional breakouts do not, however, follow organizational lines. It is thus necessary to identify for each task the organization having primary responsibility for its accomplishment, the organization(s) which must provide assistance, and those which must coordinate and/or review/approve final results of a given task. Figure 3 depicts prime responsibility. Greater detail on responsibilities is contained in Attachment 1.

5. SCHEDULES:

a. The pacing factor in the acquisition of IDAGAM is the date on which the ABS must be initiated in order to meet the OSD deadline for publishing the results of this study. Based on the estimated time to accomplish the ABS, a firm date of NLT 1 April 1974 has been established by GPFD/SAGA for initiating that portion of the Air Battle Study for which

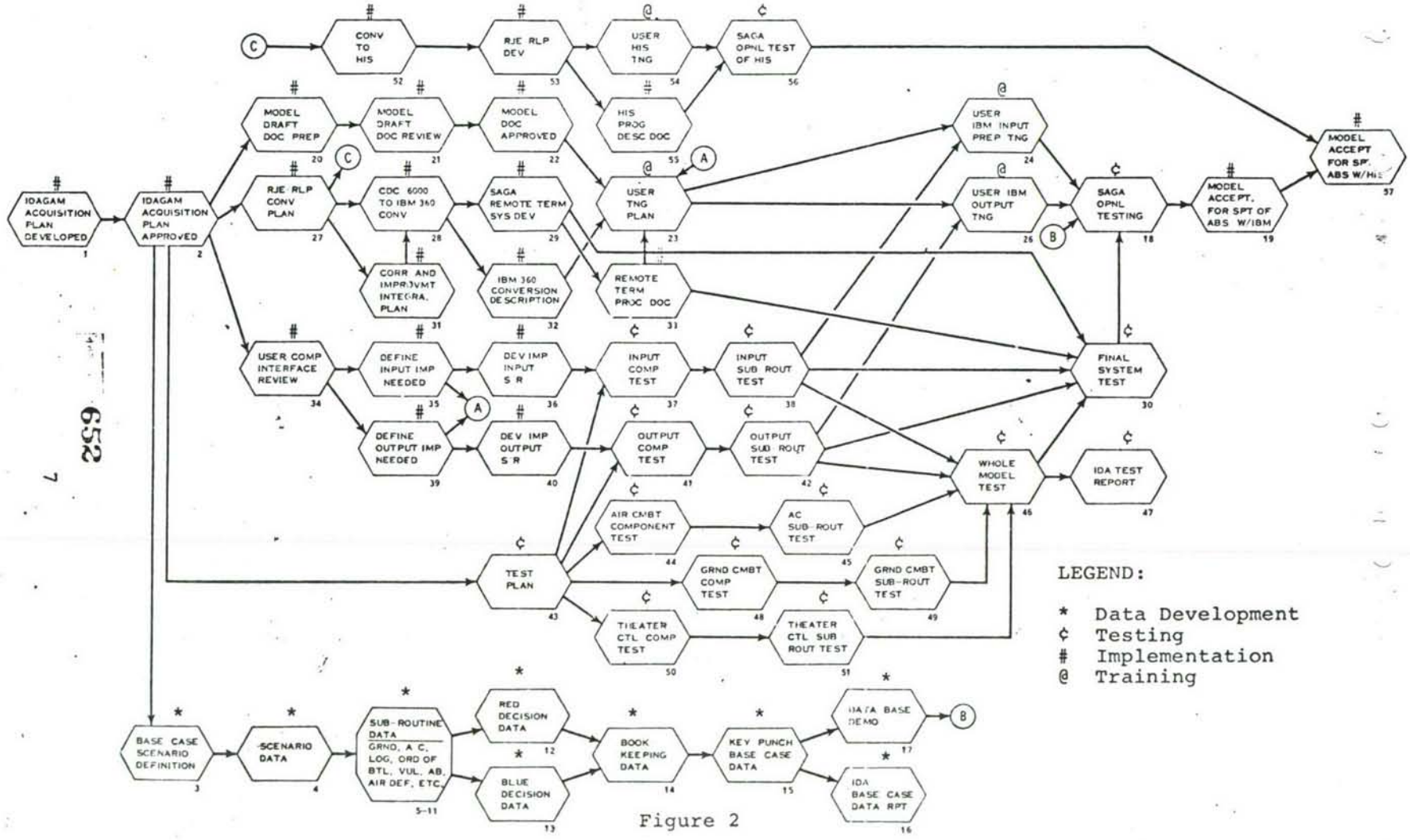


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IDAGAM I ACQUISITION ORGANIZATION

FUNCTIONAL BREAKOUT

IDAGAM I ACQUISITION PLAN



LEGEND:

* Data Development
¢ Testing
\# Implementation
@ Training

Figure 2

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RESPONSIBILITY ASSIGNMENTS

IDAGAM I ACQUISITION PLAN

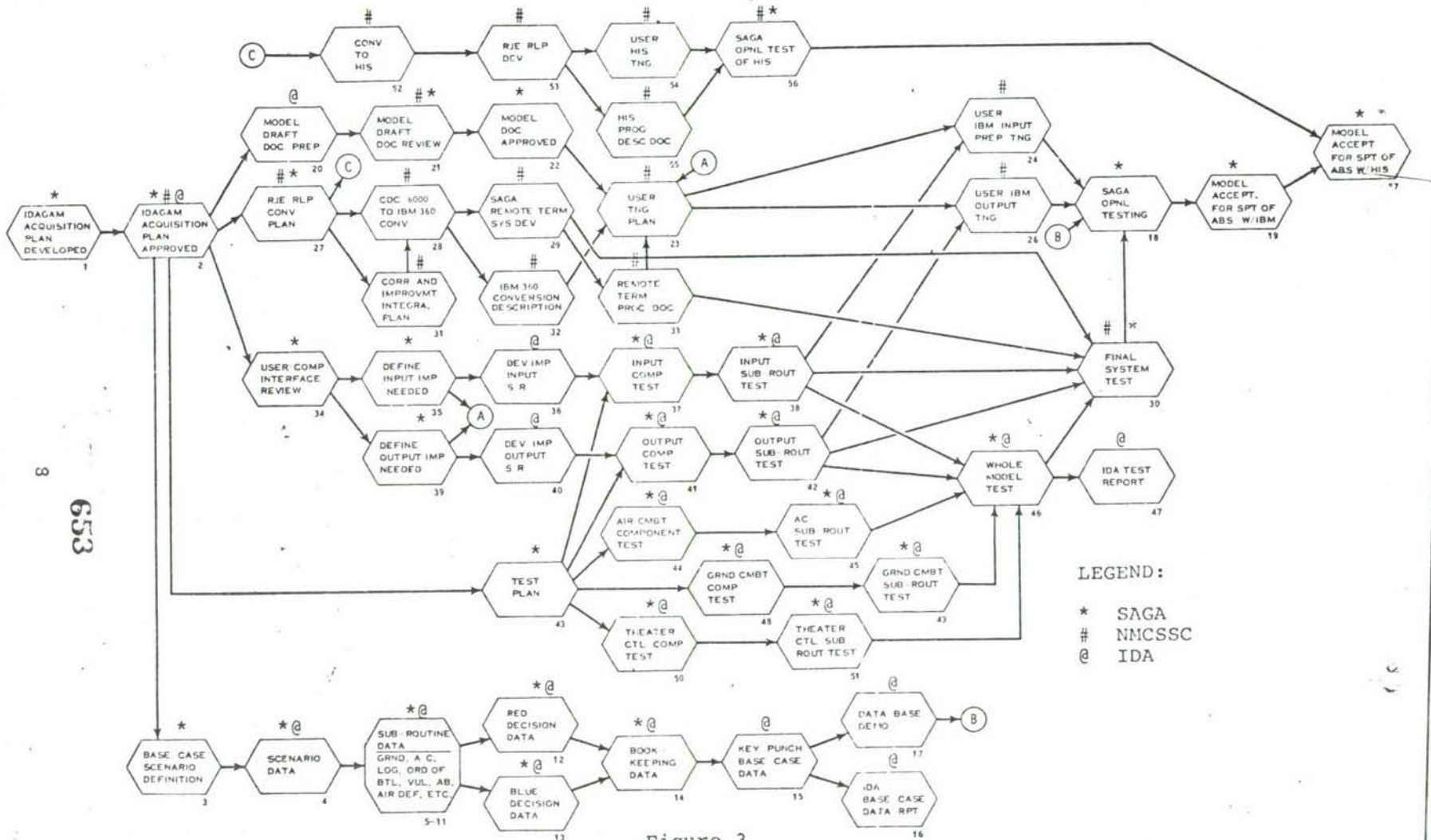


Figure 3

IDAGAM I is to be used. Thus, a somewhat compressed schedule (see Figure 4) has been developed. If adhered to, it will accomplish that goal. In Figure 4, it is noted that the majority of the identified tasks are dependent upon completion of one or more other tasks to start or, as a minimum, finalize a given task. Adherence to the time frame allocated for each of the tasks is of extreme importance if the desired end date is to be attained.

6. DECISION POINTS:

a. As stated earlier, the primary goal is to implement IDAGAM in time to support the Air Battle Study. Should circumstances preclude achieving this goal, it is imperative that delays be detected at the earliest moment, so that alternative arrangements can be made. In view of this important consideration, several dates/events have been identified at which point the progress and degree of success in timely implementation of IDAGAM will be reviewed. These events are identified in the table below:

SCHEDULE OF EVENTS

IDAGAM I ACQUISITION PLAN (Test & Implementation)

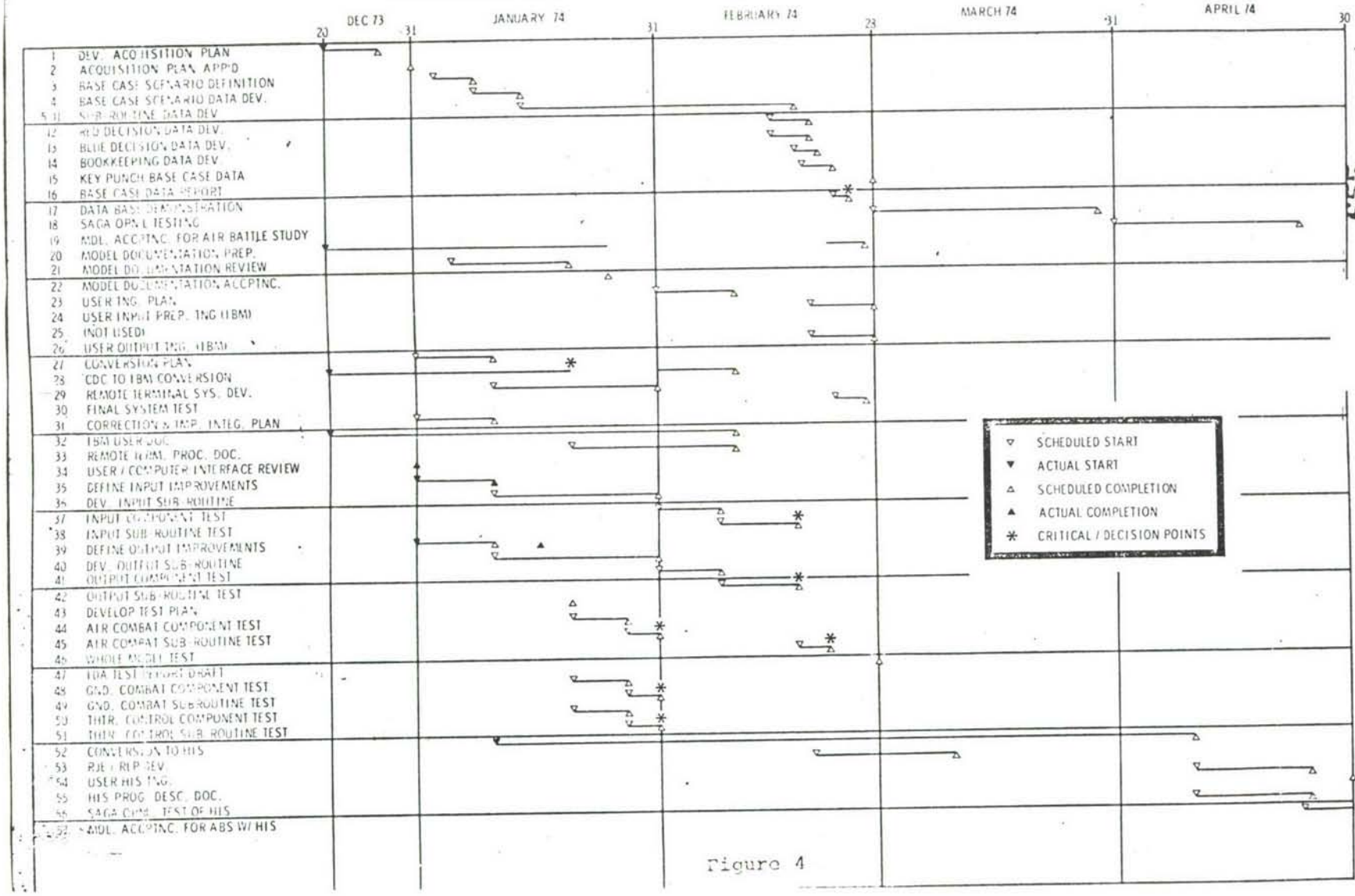


Figure 4

TABLE 1

LIST OF KEY DECISION/EVENT POINTS

Date	Event
21 Jan 74	Status of Conversion of Basic Model to IBM
31 Jan 74	Results of Testing AC,GC, and TC Sub-Routines
19 Feb 74	Results of Testing Revised Input and Output Sub-Routines
22 Feb 74	Results of IDA Test of Whole Model
25 Feb 74	Results of IDA Data Base Demonstration

b. Provided the decision at each of the above points is to continue with IDAGAM for the Air Battle Study, no further comment is necessary. On the other hand, should the decision at any of the above points be that IDAGAM cannot be made operational in time for the Air Battle Study, modification as appropriate will be made to this plan. A failure to implement IDAGAM I for this Air Battle Study does not infer that acquisition and implementation of IDAGAM is to be abandoned. To the contrary, implementation of IDAGAM will continue to be pursued in order that it can be utilized in future simulations of theater campaigns. Should the decision at any point be to abandon use of IDAGAM I for the Air Battle Study, the amount of effort which SAGA can

devote to acquiring IDAGAM I will be considerably reduced. This is necessary to ensure mission accomplishment - Completion of the Air Battle Study for the OSD deadline. It is anticipated that, if this does occur, tasking and responsibilities will remain the same, but time frames will be significantly revised.

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DISTRIBUTION:

TSD/SAGA	- 5
GPFD/SAGA	- 5
SFD/SAGA	- 1
NMCSSC (B200)	- 4
WSEG	- 4

ASSIGNMENT OF RESPONSIBILITIES

IDAGAM I ACQUISITION

P=Primary Responsibility
A=Assistance
C=Coordinate
R=Review Results

#	Preceding Event	Title	IDA	SAGA	TSD	GPFD	WSEG	NMCSSC
1	-	IDAGAM Acquisition Plan Developed	C		P	C		C
2	1	IDAGAM Acquisition Plan Approved	C	P	C	C	C	C
3	2	Base Case Scenario Definition				P		
4	3	Base Case Scenario Data Developed	P		C	A		
5	4	Ground Weapons Data Developed	P		C	A		
6	4	Aircraft Data Developed	P		C	A		
7	4	Logistic Data Developed	P		C	A		
8	4	Order of Battle Data Developed	P		C	A		
9	4	Vulnerability Data Developed	P		C	A		
10	4	Airbase Data Developed	P		C	A		
11	4	Air Defense Data Developed	P		C	A		
12	5-11	Red Decision Data Developed	P		C	A		
13	5-11	Blue Decision Data Developed	P		C	A		
14	12,13	Bookkeeping Data Developed	P		C	A		
15	14	Keypunch Base Case Data Developed	P					
16	14	Base Case Data Report Draft	P					
17	15	Data Base Demonstration	P			R		
18	17,24,25, 26,30	SAGA Operational Testing			C	P		A
19	18	Initiate Air Battle Study on IBM 360				P		A
20	2	Model Draft Documentation Preparation	P					

#	Preceding Event	Title	IDA	SAGA	TSD	GPFD	WSEG	NMCSSC
21	20	Model Draft Documentation Review			P	C		C
22	21	Model Draft Documentation Acceptance		P				
23	22,32,33, 35,39	User Training Plan			C			P
24	23,38	User IBM Input Preparation Training			C			P
26	23,42	User Output Training			C			P
27	2	Conversion Plan			P			A
28	27	CDC to IBM 360 Conversion			C			P
29	28,31	SAGA Remote Term. System Development			C			P
30	42,38,33, 29	Final System Test				R		P
31	27	Correction & Improvement Integration Plan			C			P
32	28,31	IBM Conversion Description						P
33	29	Remote Terminal Procedure Demonstration			C			P
34	2	User/Computer Interface Review			A	P		
35	34	Define Input Improvements Needed			A	P		
36	35	Dev. Improved Sub-Routine	P		C			
37	36	Input Component Test	P		C	R		
38	37	Improved Input Sub-Routine Test	P		C	R		
39	34	Define Output Improvements Needed			A	P		
40	39	Develop Improved Output Sub-Routine	P		C			
41	40,43	Output Component Test	P		C	R		
42	41	Improved Output Sub-Routine Test	P		C	R		
43	2	Test Plan			P	R		

#	Preceding Event	Title	IDA	SAGA	TSD	GPFD	WSEG	NMCSSC
44	43	Air Combat Component Test	P		C	R		
45	44	Air Combat Sub-Routine Test	P		C	R		
46	42,45,49, 51,38	Whole Model Test	P		C	R		
47	46	IDA Test Report Draft	P					
48	43	Ground Combat Component Test	P		C	R		
49	48	Ground Combat Sub-Routine Test	P		C	R		
50	43	Theater Control Component Test	P		C	R		
51	50	Theater Control Sub-Routine Test	P		C	R		
52	27	Conversion to HIS			C			P
53	52	RJE/RLP Dev.			C			P
54	53	User HIS Tng			A	C		P
55	53	HIS Program Desc. Document			C			P
56	54,55	SAGA Opnl. Test of HIS			C	R		P
57	56,19	Continue ABS w/HIS			C	P		A

SUMMARY OF SRI TACTICAL OPERATIONS MODELS & WAR GAMES

0. MODELS

Over a period of many years, Stanford Research Institute has been engaged in evaluating the effectiveness of tactical forces. As a result, considerable experience and background have been acquired, including the development of numerous models and simulations.

A few of the models mentioned in previous sections, as well as some other models of interest, are listed below.

Tactical Warfare

SRI Ground Combat Simulation (EINFALL)--Addresses questions of force composition, force balance, weapon and tactics selection, intelligence and C^3. A high degree of realism is attained by keeping track of individual combat units; however, the simulation is very efficient and easy to use.*

Balanced Force Requirements Model (BALFRAM)--Permits the rapid determination of the numbers and kinds of balanced general purpose forces and their logistics necessary to execute a specified contingency plan.

Small Arms Fire Fight Model (FIREFIGHT)--Evaluates effectiveness of alternative small arms, using the criterion of tactical mission success probability. Used to evaluate rifles, machine guns, grenade launchers, and grenades.

Artillery Effectiveness Model--Evaluates the relative capabilities of different artillery weapons.

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*Further development has been facilitated by the establishment of an informal EINFALL Users Association, whose current members are the U.K. Royal Armament Research and Development Establishment, the SHAPE Technical Centre at The Hague, and Zentrale Operations Research (ZOR) at Trier, Germany.

Air Operations

Coverage Diagram--Simulates real or generated terrain and foliage masking effects on the line-of-sight visibility about a ground site on low flying aircraft.

Low Altitude Flight Model--Determines minimum safe altitudes for aircraft flights over specified types of terrain. Establishes constraints on low altitude aircraft threats imposed by various terrain types, system errors, reaction times, acceleration limits, and turbulence effects.

Air-to-Ground Intervisibility Assessment Program (AGIAP)--Assesses line-of-sight visibility between aircraft at low altitudes and units on the ground. Integrates the Coverage Diagram (see above) and the Low Altitude Flight Model.

Global I--Evaluates the capability of aircraft to penetrate or fight their way to the target, measures their effectiveness against hard point targets, and assesses their capability to survive and complete the mission.

Mixed Air Battle Simulation (MABS II-VI)--Simulates detailed actions of air and ballistic missile attack and defense actions, consisting of SAM, AAA, and manned interceptors. Flexible as to deployment, force levels, characteristics of systems, and doctrine. Various output options available.

MABS-VIII--Expanded version of MABS, incorporating C^3, ECM, IFF, individual positioning of radars, fire units, and command posts. Specific simulation of acquisition and defense of ASM.

Air Defense Vulnerability Simulation (ADVUL)--Assesses damage inflicted on materiel and personnel of air defense targets by conventional H. E. munitions.

A Field Army Air Defense Computer Simulation Model (FAADSCOM)--Simulates detailed actions of a heterogeneous network of SAM and AAM systems against aircraft and missile attacks in the presence or absence of ECM.

Multiple Target Simulation (MTS)--Simulates the "centroid" problem. Models action of SAM aerodynamics and homing on the multiple target problem.

Reconnaissance

Combined Reconnaissance, Surveillance, and SIGINT Model (CRESS)--Evaluates the operational capabilities of photo, infrared scanner, radar, visual, laser, low light level TV, passive night vision devices, and SIGINT sensor systems in various scenarios.

Reconnaissance/Strike Cycle Queueing Model--Estimates delay time distributions for various postulated reconnaissance/strike cycles.

Damage Assessment

The SRI damage assessment system consists of several computer programs that were designed to handle a variety of specific damage assessment problems, and a series of data bases. In addition to data on worldwide military targets, the system includes population data at various levels of detail for the United States, NATO, several Warsaw Pact countries, and Japan. Detailed industrial and agricultural data bases are also included for the United States.

Costing

Safeguard Missile Cost Model (SAMCOM)--Predicts funding impact resulting from proposed changes in schedules and configurations.

Long Range Cost Model (LRC-2)--Computes time-phased costs of alternative weapons systems.

Fighter-Interceptor Cost Model (FIPCOM)--Parametric program cost model estimates total cost of a specified force of aircraft.

Other Models

Maintenance Simulation--Simulates interaction of methods of providing maintenance support involving a variable time-incremented Monte Carlo program combining different failure patterns with various levels of transportation and repair resources.

Medical Systems Analysis--A general stochastic model generating casualty inputs from an assumed battle operational situation in order to determine the degree of medical support to support the combat operation.

Air Deployment Simulator (Part of Teras System)--Deterministic simulation of strategic, tactical, and resupply airlifts.

TERAS--Supply requirements of tactical land operations.

EMBARK--Examines serialized loading of marine forces aboard amphibious ships.

TITLE: BALFRAM - Balanced Force Requirements Analysis Model

PROPONENT: Office of Naval Research (ONR, Code 462)

DEVELOPER: Stanford Research Institute, Naval Warfare Research Center

PURPOSE: BALFRAM is a computerized, analytical model of very wide applicability, including contingency planning, operational plans, force structuring (mixes), force sufficiency, budgeting, etc. It has been designed for use in the format of a high speed computer program by the operations analyst and/or military planner in order to investigate the detailed effects of all component services (Army, Navy, Marine Corps, Air Force) as these services contribute to the effectiveness of any proposed general purpose force contingency posture configured by the United States in support of its foreign policy. Such diverse weapon systems and organizations as tactical aircraft (both land and carrier based), ground forces (Army and Marine), logistic ships (e.g., Naval and merchant convoys, underway replenishment groups), Air Force cargo aircraft (e.g., C-5), submarines, VP aircraft, carrier task forces (carriers and their screens), long range surveillance aircraft, destroyer escorts, etc., have been incorporated as inputs into BALFRAM in such a way as to allow the analyst and/or planner to determine specific systems tradeoffs consistent with the scenario dependent roles and missions of any proposed general purpose force under consideration.

GENERAL DESCRIPTION: BALFRAM is a multisided model, using as many sides as the user desires. It involves land, air, and sea forces, as well as civilian personnel or any other type of participant desired. It can consider any level of aggregation from individual elements to convoys, division forces, air wings, task forces, etc. Events may also be considered on any basis from individual engagements to worldwide contingencies, operational plans, total defense posture, etc.

The model is deterministic. Simulated time is treated variously, on the basis of time step or event store, depending on the aspect of the problem under consideration. Lanchester equations (linear and/or square law) are the primary solution technique used.

INPUT: All orders of battle, threshholds of survival, firepowers, deployments, mobilities, tactics, strategies, geography, and battlefield and/or campaign objectives characteristic of both red and blue ground/air/sea units. These parameters define the boundary conditions of the set of equations used in the solution methodology for any particular BALFRAM general purpose force exercise.

OUTPUT: Very wide variety of output options. Essentially any data generated by BALFRAM internally can be output.

MODEL LIMITATIONS:

- The model is deterministic.
- Command, control and communications factors are not included.

HARDWARE:

- Computer: IBM 360; CDC 6400, 6600.
- Operating System: OS (IBM); SCOPE 3.3 (CDC).
- Minimum Storage Required: 150K (IBM); 100K (CDC).
- Peripheral Equipment: One disk, or one tape.

SOFTWARE:

- Programming Language: FORTRAN IV
- Documentation: "Force Requirements Analysis Model," FLD/GP 15/7 (AD-876007L).
- Both user's documentation and technical documentation are complete, in the NAVCOSSACT format.

TIME REQUIREMENTS:

- 1 month to acquire base data.
- Up to three man-months to structure data in model input format.
- 5-15 seconds CPU time per model cycle.
- A few weeks learning time for users (experienced personnel).
- Some weeks to analyze and evaluate results, depending on problem.

SECURITY CLASSIFICATION: UNCLASSIFIED.

TIMES USED SINCE 1969: Several hundred runs.

USERS:

- Principal: CINCPAC J-5
- Other: ADC/S (Programs), HQMC;
  ADC/S (Plans), HQMC;
  AC/S, G-3, HQFMFPAC.

POINT OF CONTACT: Major John M. Hey
Systems Analysis
Marine Corps Headquarters
Arlington Annex
Columbia Pike & Arlington Bridge Road
Arlington, Virginia 20370
Telephone: OX 4-2030

MISCELLANEOUS: It is currently planned to add a sequential analysis capability to the model.

KEYWORD LISTING: Analytical Model; General War; Limited War; Politico-Military; Logistics; Damage Assessment/Weapons Effectiveness; Land Forces; Air Forces; Sea Forces; Civilians; Computerized; Multisided; Deterministic; Time Step; Event Store.

STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

Naval Warfare Research Center

BALANCED FORCE REQUIREMENTS ANALYSIS METHODOLOGY

(BALFRAM)

The Balanced Force Requirements Analysis Methodology (BALFRAM) is a theater level model which is designed to provide a framework within which problems of balanced force requirements or capabilities can be analyzed. The software system furnishes a technique for modeling the simultaneous engagement of opposing land, sea, and air forces and estimating the expected value outcome of such engagements, thus assisting in the evaluation of the relative effectiveness of alternative force levels, mixes, deployments, and utilizations. The model also includes optional provisions for generating game theoretic solutions to problems of resource allocation and for statistical sensitivity analysis to quantify the relationship between model input and model output.

BALFRAM is constructed so that the user defines the problem or scenario of interest from an operational standpoint and translates it into BALFRAM terms. He also provides the operational logic (strategy and tactics) that will be applied to the situation and translates this logic into BALFRAM terms. The translations are accomplished by specific user inputs which assemble the appropriate components of the BALFRAM software. Using the BALFRAM system as a tool, the user subsequently constructs, with output feedback, a notional model that embodies his abstraction of the real world process. Even after the initial model construct has been completed, modifications can be effected as insights into a particular problem are obtained. Subsequent sensitivity analyses, tradeoffs, etc. can be made. This iterative feedback process enables the user to construct a BALFRAM model that has analytical relevance to military planning problems.

In order to use BALFRAM, a real world scenario must be translated into a congruous BALFRAM scenario. Scenario geography is abstracted in

terms of nodal points and lines of access between nodes. The nodal points can represent either defined geographic areas or individual locations within an area. Areas represented by a node can range in size from that required for an army squad to that required for a naval or an air battle. The lines of access between nodes and their associated distances represent the lines of communication over which the forces and logistics of both sides must move and provide prescribed paths for combat units to follow in the course of an engagement or campaign. The nodal network can be as detailed or general as required for the problem under consideration. Given a specific network of nodes, a preprocessing program solves for the shortest distance route between any two points in the nodal network. The nature of the network allows the user to input the peculiarities of geography and topography when assessing the effects of force location and mobility on scenario outcome. Additionally, the distribution of forces as a function of time over nodes and lines of access can apply to real world problems of possession, control, or entry to a given territory during the course of a scenario.

In addition to scenario geography, the characteristics of the forces involved in the hostilities must be defined. Force characteristics as input to the BALFRAM system refer to the numbers and types of units that each side can ultimately commit during the scenario, their mobility or rate at which each of the units can move over the scenario geography, and their effectiveness or lethality in terms of the ability to inflict attrition on opposing units. Each unit is defined as a separate attrition entity. The unit is a notional concept, in that individual members of a specified unit are assumed to have similar attrition capabilities, mobility, and other characteristics. An individual unit can be input as a division force equivalent or several divisions, a number of airplanes, a ship, or a large naval force. The attrition capabilities for units of either

side are average rates; however, as described in subsequent sections of this report, the computational method in which these rates are used is selected by the user.

Finally, the most complex input, the contingency logic, must be supplied. Contingency logic relates to the way in which available forces are to be used, both in the context of initial force deployment policies and in subsequent utilization. As an example of initial force deployment policies, one might consider what proportion of available ground forces are to be assigned various geographic objectives and what specific mission allocations, such as close air support or air defense, should be made for tactical aircraft. In addition to the initial way in which available forces are to be used, it may be necessary to alter deployment policies or mission allocations contingent upon some set of circumstances which could occur. These contingent activities provide the operational priorities and movement logic which govern the combat units as the scenario progresses.

Contingent activities can be stipulated in several different ways. The logic input statements which effect these changes are of a general form: if some condition is true, then specified units do the following. The "condition" part of the statement may be the location of a friendly or enemy unit, the amount of attrition suffered by either, or simply the passage of time. The "do the following" portion of the statement can relate to force movements, a specific mission allocation, or a change in characteristics of the forces involved.

When a BALFRAM scenario computer run is started, the program begins to move available units over the scenario geography. As force interactions begin to occur, the program calculates the attrition suffered by each side during the various unit interactions. The results of these calculations for individual unit interactions are recorded, and at the end of each

specified time period, a detailed battle history, which shows the strength and location of each unit as well as its current and next mission assignment, is printed. The process is repeated until one side or the other is defeated, as defined by a user input which specifies the level to which enumerated units must be attrited before they are considered nonviable or defeated. Once the battle is terminated, it is possible to repeat the entire process, automatically effecting changes in the original force characteristics or deployment policies.

Two types of printed output can result from a BALFRAM run; these are the "battle history" and the "end of campaign summary." Both include, as a first block of output data, a listing of the BALFRAM descriptors exactly as they occur in the input data set as well as a listing of all the descriptors as processed by the program. The user can obtain or suppress the battle history but has no control over its content. The battle history provides a chronological record of the scenario which details the location and next objective of forces, location and status of battles, and the size of forces involved at each battle step. The end of campaign summary, in contrast, is controlled by the user with respect to both generation and content. Content options include such data as BLUE forces surviving, RED forces surviving, the difference between BLUE and RED forces surviving, casualties resulting from exogenous firepower applied by BLUE and RED, and the duration of battle.

STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

EINFALL: A NEW LAND BATTLE SIMULATION
(Revised)

By

Wayne B. White

Howard H. Metcalfe

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INTRODUCTION

EINFALL is a battle simulation that allows fighting units to move and fight in the most intricate spatial patterns, operating as individual units within organized groups, pursuing objectives and carrying out orders given to them by a complex hierarchy of command. The sequences of commands followed are not fixed, but are continually modified in response to unpredictable successes or failures, and in response to the tactical intelligence continually flowing in from various areas and organizations. In spite of the high degree of realism attained, the simulation is easy to use, and very efficient in terms of input effort and computer time. The user feels he is manipulating forces and tactics that are directly correlated with reality; outputs seem to contain more information than went into the computer - in contrast to some war models that produce nothing that was not known to the umpire or codified in the rules beforehand.

The EINFALL concept was developed at the Zentrale Operations Research (ZOR) of the Ministry of Defense of the Federal Republic of Germany, at Trier. The development of the model was necessary in order that questions of force composition, force balance, weapons and tactics could be answered without the large expenditures of time and manpower necessary in map-type wargames. The computer model was developed jointly by W. B. White of SRI (ZOR), and by H. H. Metcalfe of the Planning Research Corporation of Los Angeles, who also did the complete programming of the Mark I and Mark IA models. Further development of the model has been facilitated by the establishment of an informal EINFALL Users Association, whose principal current members are the U.K. Royal Armament Research and Development Establishment, the SHAPE Technical Centre at The Hague, and ZOR. This cooperative development has produced, at the present time, the Mark II version of EINFALL herein described. The Mark II modification was programmed for R.A.R.D.E. by Graham G. Hawker and Brian H. Hall of Scientific Control Systems Ltd. (formerly C-E-I-R U.K.); the officer responsible for the project at R.A.R.D.E. was Mr. D. W. Beeching.

General Characteristics of the Model

Probably the most important feature of the model is the manipulation within a computer of large numbers of individual fighting units characterized in realistic physical terms. Weapons have, for example, maximum firing ranges, and within those ranges specified variations of lethality with distance. Munitions have specified lethal radii around their points of detonation. Maximum firing rates are specified. Units have a specified vulnerability. All of these characteristics can be made to depend on the local physical environment, on the status of the unit, and on the type of enemy unit engaging or being engaged.

Already this implies that units may be in any of a number of tactical states. A unit for example may be halted, taking cover, digging in, entrenched, defending, marching, advancing, assaulting, withdrawing, regrouping, emplaning, flying, or deplaning. Frequently a delay time will be associated with a change of status, together with changes in the specified limits on speed, firing capability, and vulnerability. Tactical parameters may also change simply because a unit has moved into a different physical environment, or because time has moved - for example, darkness may have fallen on the battlefield.

Environmental factors are attached to designated local areas. In the simulation, area shapes are limited to rectangles and circles or sectors of circles, oriented in any desired position on the battlefield. The location of an area is not necessarily fixed, and an area may be "attached" to a fighting unit or organization that may be moving in a complicated pattern. Likewise, the size of a circular area is not necessarily fixed, but can be made to correspond with the radius of dispersion of a collection of fighting units, or with the radius of dispersion of a barrage of artillery rounds. Also, various distributions of points within areas are available for producing desired patterns for site selection, for aiming point dispersion, for representing probability of detection, and so on. For example, peripheral deployment can be specified, or deployment along a circular arc, or random

or uniform deployment, or deployment toward the front or rear of an area, or deployment that is functionally dependent on the range of the weapon deployed.

The key to the richness of the model is the organization of the independent but subordinate units within a command structure for the purpose of achieving the desired objective in an organized way. The command structure can be as elaborate as the analyst desires, subject only to the restriction that no more than five levels of command be represented simultaneously. The usual tree-like structure of command can be specified very easily, with the computer doing the routine work of duplicating identical units as necessary and arranging them in the designated hierarchy.

With the command structure established and the force elements assigned their proper place in the structure, fighting units act as organized entities carrying out the orders issued by any command having cognizance over those units (actually, by any command assuming cognizance over them). In addition to organization by command, it is possible to control units by class and by location. For example, certain orders can be imposed on one type of weapon regardless of which command it reports to; or imposed on weapons in a particular area regardless of whose weapons they are. But, as in real life, the most common form of control is by superior command.

A command then represents all the fighting elements (as well as passive elements) assigned to that command, and also represents the commander himself, with his intelligence apparatus, his estimate of the situation, his judgment, and the continuing series of orders which he issues. In representing the collection of subordinate units in a command, the simulation maintains current information on the position and status of every fighting unit in the command, on the total attrition and rate of attrition experienced by the command, the position of the center of gravity of all the units in the command, the rate and direction of movement of the center of gravity, and the dispersion of units from the center of gravity.

Under the control of the analyst, the commander gets information of this sort on his own unit, on other specified friendly and enemy commands, and on collections of units in specified areas. For intelligence gathering, the specified areas may be fixed, or may move as if representing patrols or reconnaissance devices.

On the basis of the information available to the commanders, they will in simulation make decisions and issue appropriate orders:

... if my own attrition reaches 15%, my units will halt and take cover, and I will request artillery support from 46th Batallion against Hill 209 ...

... if total enemy strength within a radius of 10 km of my position is found to exceed xxx, A-Company will remain in position while B-Company advances to a flanking position in Area Beartrap, and C-Company closes with the enemy force ...

... we will move southeastward across the Red River Basin, choosing the areas of least enemy strength, while we call for close air support against enemy concentrations where they are most dense ...

... Tank Companies A and B are to proceed at full speed northward on opposite sides of the valley, stopping to engage enemy tanks only if groups of three or more are encountered. If the rate of advance of either column falls below 15 km/hr, it shall change course to move in behind the other column ...

... perimeter defenses have been set up in a roughly circular pattern around XYZ airstrip. The position is under heavy artillery and mortar fire from all sides, and casualties and infantry units are being evacuated by air as fast as possible. Fortunately, enemy anti-aircraft fire is light. At 2300 hrs, when evacuation is scheduled to be complete, all remaining artillery and missile units will concentrate fire on points in the perimeter area within 1000 yards of Route 53, and at 2330 all mobile units will try for a breakout, tanks in front. Good luck ...

... the advance to support the defense of the railway bridge has been stopped by the unexpected encounter of enemy grenadier units in Vogelsang Forest flanking the route of advance. 407th and 409th Light Howitzer Batteries will maintain barrage fire of anti-personnel rounds into the forest area until drop-time of Airborne Company D onto the slope above the area at 1510 ...

... enemy reinforcement of units opposing 39th Brigade has been observed. If the force ratio, which is now approximately 1.5 to 1, reaches 2 to 1, Brigade is to retire to pre-prepared positions at Line L, and ADMs are to be blown at the three prepared highway interchange points ...

As can be seen, the elaboration possible in the construction of scenarios is mainly limited by the imagination of the user and the needs of the analysis. Because of computer capacity, there are limits imposed on the total numbers of individual fighting elements, weapon types, environmental areas, command units, orders, and so on - but these are not particularly stringent. Probably more restrictive are the limits inherent in the analyst himself, in the face of the almost limitless array of unpredictable circumstances that can arise during the play of even a simple game. The simulation is designed for non-interactive play. That is, the computer does not stop in the middle of a run to allow the user to make new choices or give additional instructions. With the computer speeds attainable, and with automatic parameter exploration, it is more efficient to let a given set of plays run to completion, analyze the results and then, if necessary, make new runs with different instructions. But this means that the user must visualize beforehand the whole array of possible events and prepare contingent orders and instructions to avoid unreasonable or meaningless sequences of play. For this reason, the period of action represented in one computer run is usually short - minutes, or at most a few hours of battle - so that the tree-like branching of contingencies is kept within manageable limits.

User Convenience

Generally, the user needs only to make selections from a comfortable number of standard instructions which are more in the nature of directives. The computer, acting somewhat as a subordinate staff, expands these general directives into the myriad detailed instructions that govern the positioning, moving, and activity of individual troops, weapons and other equipment. The user, like the Commanding General, does not have to issue specific orders to each man in his command. The general 'directives' that can be established by the user within any desired set of organizational units, cover the following types of variable:

- the balance of priority between advancing and pausing to engage enemy units
- the deployment patterns
- the balance of priority between advancing as fast as possible and maintaining deployment patterns
- the relative engagement priority for various classes of enemy units
- the balance of priority between targets of opportunity and targets of higher value expected to be encountered later
- the choice between point fire and area fire
- the choice between attacking the enemy where he is strongest or where he is weakest
- the choice of opening engagement range
- the quantity of intelligence obtained, or the extent of reconnaissance
- the quality of the commanders' judgment - that is, the fraction of their decisions which are incorrect or irrational

Also, the computer provides automatic exploration of the parameters describing the physical and tactical characteristics of the weapons and other equipment, if this desired. Some information is provided for logistics analysis: the total movement of all units, by type, is recorded, as well as the total expenditure of ammunition. The usual print-outs are available: complete event listings, or position and attrition reports at stated intervals, and overall statistical summaries.

Applications

Although the present simulations were designed as experimental models, they have proved adequate for a large range of applications, and the exploitation of their potential is far from complete.

One of the first subjects to which the simulation was applied was the evaluation of various mathematical models of land combat - in particular, the Lanchester equations. For this purpose, a large number of rather simple land battles were set up involving tanks or other mobile medium-range artillery. The situations were carefully designed to be perfectly symmetrical with respect to everything except the quantities of weapons involved. The opposing forces were given identical weapons, identical sensors, identical battle orders, and moved into engagement in symmetrical patterns. Attrition histories were observed for various force ratios, as well as for different maximum ranges, different firing rates, and different weapon movement rates. As would be expected, the dominant factor was force ratio, and for the same force ratio, weapon characteristics had little effect on attrition history as long as both sides were given the same weapon and used the same tactics. For such cases, the attrition history, after random fluctuations were taken out, followed very closely a Lanchester-like law of the form

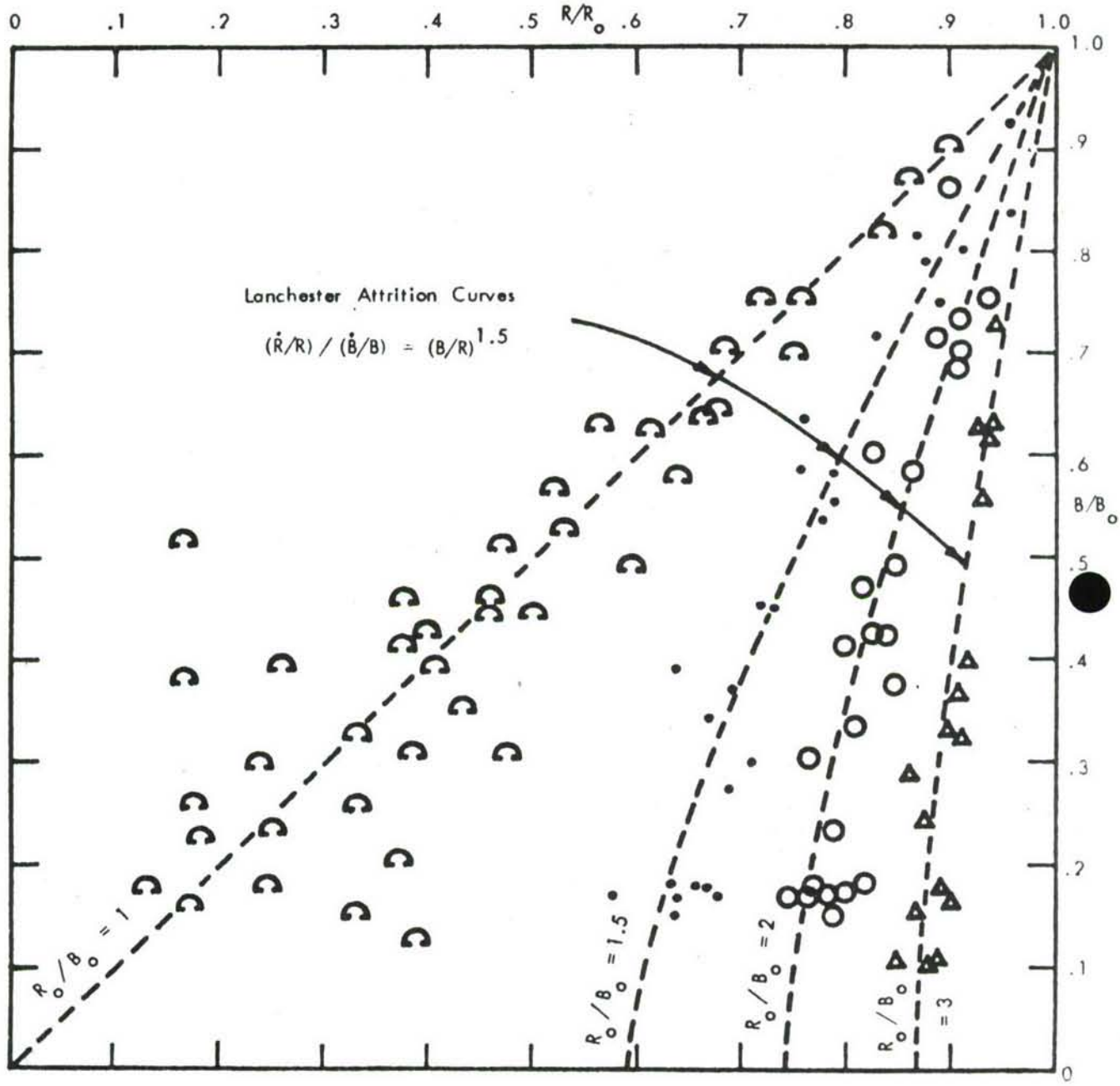
$$(\dot{R}/R) \;/\; (\dot{B}/B) \;=\; (B/R)^{\alpha}$$

with α taking on a value of about 1.5 or 1.6 - that is, intermediate between the Lanchester Linear and Lanchester Square Laws (see Illustration). These results in turn allowed a mathematical model to be used in the development of optimum micro-tactics to be tested in more complex simulations.

EINFALL, or improved simulations of this class, appear to provide a powerful tool for the analysis of combat effectiveness, weapon design, tactics, the use of battlefield intelligence, and the contribution of command.

ATTRITION HISTORIES -- EINFALL TANK BATTLES

Identical Opposed Weapons, Unequal Quantities



EINFALL Tank Battles, 15 tanks vs 15 tanks

EINFALL Tank Battles, 18 tanks vs 12 tanks

EINFALL Tank Battles, 24 tanks vs 12 tanks

EINFALL Tank Battles, 27 tanks vs 9 tanks

VRI WP 75-4
18 June 1975

HISTORY, DEVELOPMENTAL APPROACH, AND CONTENT OF THE VECTOR SERIES OF THEATER-LEVEL COMBAT MODELS

Prepared for the

GAMING AND SIMULATION GROUP (C-5)

of the

35th MORS SYMPOSIUM

by

VECTOR RESEARCH, INCORPORATED

Ann Arbor, Michigan

1.0 INTRODUCTION

This paper is intended to provide background information regarding the VECTOR series of models for participants in the working group on Gaming and Simulation at the 35th MORS. The paper discusses the program of development of the models (in section 2.0) and the approach used to represent theater-level combat in these models (in section 3.0). An appendix gives a more detailed description of the models themselves and briefly discusses some experience with them. The value of the models to prospective users will be discussed in the working group sessions.

2.0 BACKGROUND

Prior to 1972 models which have been used to describe large-scale, joint services, theater-level warfare have been aggregated and macroscopic in nature in that they aggregated individual weapon system effects at the theater or field army level by using a single strength factor (known as the "firepower score") to describe the theater-sized units. Although the aggregated "firepower score" models are relatively easy to use, they are known to contain a large number of technical and data problems.[1] In brief, some of the deficiencies are associated with

(1) the use of the "firepower score" force ratio concept as the principal means of driving the attrition process, and

(2) the use of the "firepower score" force ratio concept to determine the rate of FEBA movement.

Two of the most serious problems in the "firepower score" models are

(1) the inability of the models to reflect changes in detailed tactical phenomena (e.g., calls for air support by units engaged at the FEBA), and

(2) the inability of the models to reflect reasonably the significantly different attrition of different weapon systems (which leads to deficiencies in the dynamic modeling of campaigns of any duration, and to problems in producing useful output measures).

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[1]See Jacob A. Stockfisch, Methodologies for General Purpose Forces Planning, Volume X: Firepower Score Review, WSEG Report 165, April 1971 (SECRET) for a detailed discussion of many of these problems with the use of firepower score concepts.

The objective of the VECTOR model development program has been to demonstrate the feasibility of constructing a campaign model which:

(1) does not use the "firepower score" force ratio concept of attrition, but rather models attrition in a way that reflects the internal dynamics of the combat activity and relates to specific weapon system parameters and tactics considered important in small unit engagements,

(2) disaggregates the Army by explicitly considering many weapon system types that can individually be attrited in maneuver battalions, as well as artillery, air defense, and helicopter systems,

(3) drives the FEBA movement activity by other than the "firepower score" force ratio concept,

(4) treats "non-integral" FEBA situations, and

(5) considers all relevant combat and non-combat processes.

The VECTOR models are being produced by Vector Research, Incorporated (VRI) in a sequential development program sponsored by the Weapons Systems Evaluation Group (WSEG). The first version of the model -- VECTOR-0 -- was a prototype designed to demonstrate the feasibility of producing a model with the features described above. With the successful testing of VECTOR-0 in the summer of 1973, VECTOR-1 -- the first production version of the model -- was developed and tested the following year. VECTOR-1 contains some purposeful simplifications particularly in the area of command, control, communications, and intelligence/target acquisition. As a consequence, a second production version -- VECTOR-2 -- is currently

under development. This version will not only add the above major areas omitted in VECTOR-1 but will also enrich processes currently included in it based on the stated priorities of several Department of Defense agencies. It is scheduled for completion in September 1975. The analytic structure developed for VECTOR-2 is expected to lead to the development of VECTOR-3 in FY 76 which will be able to represent realistically non-integral FEBA situations such as penetrations, envelopments, air drops, flank combat, exploitations, etc. and the important concept of "critical events." The existence of VECTOR-3 should, in turn, allow for the future development of a VECTOR model which can represent tactical nuclear warfare realistically. This sequential program thus allows for the gradual development and testing of improved versions of the model representing a broader spectrum of theater-level warfare activities.

3.0 APPROACH

The conceptual philosophy and approach that we adopted for development of the VECTOR models was influenced by a number of important technical considerations. First, the firepower score may be thought of technically as a "many-to-one" transformation of the many effects and systems involved in theater-level combat into a single number which essentially drives both the attrition and movement processes. Early work at VRI with small unit combat modeling and analyses indicated that this type of transformation tends to mask many significant interactions among the weapons systems effects, terrain characteristics, organization for combat and employment tactics. In addition, some mathematical research we did at VRI indicated that no logically correct procedure could be developed to perform the inverse transformation on the firepower score attrition results in order to determine which systems were attrited during the course of a battle.

For these reasons, VRI selected a somewhat different approach in developing the VECTOR models. Rather than attempting to aggregate effects, VRI chose to include in the models (and dynamically keep track of) explicit representation of the various systems and processes involved in theater-level combat, and to describe these systems and processes in terms of measurable physical and behavioral variables. Hence, the VECTOR models include detailed representations of the following:

- types of systems (Inventories are maintained for twelve types of maneuver force weapons, fixed-wing aircraft, attack helicopters,

air defense systems, field artillery systems, and the personnel associated with all of these systems.),

- organization for combat (Cross attached task forces at various levels are organized for their assigned mission; aircraft are organized into specific flights; ADA are organized for target site, area, or duel defense; artillery is organized into direct and general support; and complete command hierarchy is included.),
- battlefield representation (Separated FEBAs, objectives, defensible positions, terrain effects, boundaries, obstacles, man-made features, and natural terrain features are all explicitly represented.),
- attrition processes (Models are used which represent the attrition of specific weapon systems as a function of their physical characteristics and tactical employment. The models consider detailed weapon system parameters, e.g., acquisition rates, firing dispersions, firing times, projectile flight times, weapon reliabilities, kill probabilities, etc.; weapon-target allocation procedures; terrain line-of-sight interactions; range dependencies; scheduled and unscheduled fire support interactions; and other details to represent attrition realistically.),
- tactics and tactical behavior (Flexible, easily modified tactical decision rules are used to simulate tactical decisions and related combat behavior. Some of the decisions modeled include scheduled and unscheduled fire support allocations; type of maneuver unit combat to engage in; fronting decisions; allocation and dynamic reassignment of personnel, weapons and supplies to sectors and

units; terrain bypassing; reserve commitment; and other decisions deemed relevant to representing combat and support activities realistically.),

- movement processes (The models explicitly represent air flights -- both attack and interceptor aircraft -- and maneuver-unit -- both front line and reserve -- movement. FEBA movement is not a function of aggregated force ratios but instead is treated dynamically for individual battalion-level task forces as a function of their combat activities.).

An overview of the model content and some experience with it is given in the attached appendix. The usefulness of models structured with this approach will be discussed at the working group meeting.

APPENDIX

OVERVIEW OF THE VECTOR MODELS

1.0 INTRODUCTION

The purpose of this appendix is to present an overview description of the VECTOR models developed by Vector Research, Incorporated, for the Weapons Systems Evaluation Group (WSEG). The models are intended to describe the joint activities of NATO army units and air force tactical aircraft engaging advancing threat forces who are also supported by tactical aircraft. The models are for use in estimating net assessments and in generating data to make trade-offs among the various forces and systems involved in such an engagement.

VECTOR-0, a first version of the model (which was originally called BATTLE[1]), was delivered to the WSEG in May 1973, and some initial development tests were performed during June and July of that year. Although it eliminated some of the deficiencies in existing models, it is important to recognize that the model delivered to the WSEG then was a prototype which contained many purposeful simplifications. VECTOR-1, a first production version of the model was delivered and tested in early 1974. This version still retains some major simplifications some of which are being removed in the current development of VECTOR-2, which is scheduled for completion in September of this year. The next three sections of this appendix describe the contents of VECTOR-0 and VECTOR-1. Section 5.0 describes extensions currently being implemented in VECTOR-2. Section 6.0 gives some results of initial uses of the models.

2.0 THEATER BATTLEFIELD REPRESENTED

2.1 Geometry: The front or FEBA in VECTOR-1 is divided into parallel *segments* so that the FEBA is considered piecewise linear over the total theater. Maneuver forces at the FEBA are associated with these segments. Each segment is assumed to be of such a length that it will accomodate a battalion-sized maneuver force (i.e., 2000 - 8000 meters) and, accordingly, the area about each segment is referred to as a "battalion area". The total theater battlefield is divided into *sectors* to provide for better representation of the spatial allocation of forces. The sectors are parallel areas that run from the FEBA all the way back to the rear area. The model may contain up to ten of these sectors; and, accordingly, they may be thought of as areas that might accomodate corps-sized forces.[2] Reserves for maneuver forces at the FEBA (referred to as maneuver forces in reserve) are associated with each of the sectors, as are all rear area forces (artillery, air defense artillery, tactical aircraft, etc.).[3]

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[1] BAttalion Through Theater Level Engagement.

[2] The initial development tests were conducted with a one-sector version, i.e., the theater was treated as one large sector.

[3] DIVOPS, a more detailed division-level version, had been constructed and used with reserves and rear area forces located within brigades or at higher echelons and located in more detail as to depth from the front. This additional detail is also included in VECTOR-2.

2.2 Terrain: Terrain areas in the model are classified into up to 25 categories (based on five visibility categories and five trafficability categories). In addition, linear or small terrain *features* such as rivers, fortifications or other barriers, hill ranges, or urban conglomerations may be located within any terrain area. Terrain must be uniformly classified as to area type in any cross-section of a sector, but features need not cross an entire sector.

2.3 Model Time: Model time is discrete (integer valued) measuring model time periods. These may, but need not, correspond to days (e.g., they may be considered six-hour time periods).[1] Model data must be consistent with the period definition used.

2.4 Forces Represented: The model considers maneuver forces at the FEBA (one Blue battalion task force in each battalion area and appropriate Red units allocated to face it), maneuver forces in reserve, artillery forces, attack helicopters, air defense artillery, tactical fixed-wing air forces, and service support forces. Maneuver forces (both at the FEBA and in reserve) can contain up to nine types of weapon systems (which have typically been played as two types of armor (tank) systems, three types of antitank systems, armored personnel carriers, infantry with heavy automatic weapons, mortars or similar area fire weapons, and infantry with basic rifle squad weapons) and personnel associated with the different weapon systems. Artillery forces can contain one weapon system class and and personnel associated with that system; attack helicopters can contain one weapon system class and personnel associated with it. Air defense artillery forces can contain short-range air defense systems, long-range air defense systems, and personnel associated with these.[2] The tactical air forces are comprised of up to seven user-selected types of fixed-wing aircraft and personnel associated with them. (Aircraft shelters for any or all types of aircraft may also be played.) Service support forces are made up of personnel. The model continually keeps track of the number of weapon systems by type and personnel in each of the Red and Blue maneuver forces at the FEBA and the maneuver forces in reserve in each sector. Additionally, the numbers of weapon systems are separately retained for artillery forces, attack helicopter forces, air defense artillery forces, tactical air forces, and service support forces for each of the sectors. In addition to these forces, DIVOPS plays observers and target acquisition systems in association with the forces. It maintains information on all expected target acquisitions at each time step by observer and target type and location.

2.5 Supplies Represented: Supplies of the following kinds are separately represented in the model: ammunition for each army weapon system type, ordnance (in user-specified categories) for aircraft, aviation gasoline and associated POL (for fixed-wing aircraft and attack helicopters), POL for ground systems, mines, and other supplies. Ammunition is assigned to (and separately kept track of by type at each place) individual battalion area maneuver forces, individual artillery forces, individual attack helicopter forces, individual air defense artillery forces, individual tactical

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[1]Time periods as small as 15 minutes have been used in DIVOPS.

[2]DIVOPS has been used with up to four types of artillery and six types of air defense artillery separately treated. VECTOR-2 will also include these additional systems.

air forces, sector stores,[1] and theater stores.[1] POL is assigned to individual battalion-area maneuver forces, sector air forces, sector stores,[1] and theater stores.[1] Finally, the "other" supply category is assigned to scetor stores and theater stores.

2.6 Plans and Intentions: For each time period in VECTOR-1, each maneuver force at the FEBA has a *plan* which is established on the basis of the overall situation by user-input decision rules which will be discussed below. The set of possible plan values is capable of user definition. A set which has proven reasonable for several cases run so far is: move forward; hold; hold, delay if moved on; and hold, withdraw if moved on. The list of plans can be expanded as input by the user. It has in some cases included additional features such as: "If successful when moving forward, do not move more than 10 kilometers," Each side has an *intention* in each sector which currently may be to attack or defend.

2.7 Activities Represented: The model separately represents activities for each of the forces. Maneuver forces at the FEBA can be engaged in either a Blue *assault* (Red *hasty defense*), a Blue *advance* (Red *delay*), a Blue *pursuit* (Red *withdrawal*), *relative inaction*, Red *assault* (Blue *hasty defense*), Red *advance* (Blue *delay*), and a Red *pursuit* (Blue *withdrawal*). Artillery forces can simultaneously be engaged in (by percent allocation) counter-battery fire, direct support of engaged forces (preparatory fire, counter-preparatory fire, calls for additional fire to battalion area units, and final protective fire), and other fires[2] on other targets such as reserves, etc. Attack helicopters engage in support of engaged forces (either in delay, withdrawal, or assaults), and air defense artillery engage in air defense fires. The tactical air forces can simultaneously engage in the following activities: air base attack; combat air support (against FEBA maneuver forces, reserve maneuver forces, artillery, and air defense artillery); suppression of air defense artillery; interdiction against other user-chosen rear area targets such as convoys, depots, etc.; escort of the above missions; and air defense. The service support forces perform the transfer of supplies (and also serve as targets).

In this section we have discussed what is represented in the model in terms of time, forces (type, composition, and location), supply types and levels, plans and intentions, and activities. Each of these are variables in the model which may change from time period to time period. At the end of each time period we can look at values of these variables and think of them as representing a description of the battle at that point in time; i.e., a snapshot of the battle at that time. Thus, the values of these variables describe the "state" of the model battle at some point in time and are thus referred to as "state" variables. The processes which cause changes in these state variables are discussed in the following section of this overview.

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[1]These are intended to simulate physically removable supplies which the tactical decision rules may not make immediately available.

[2]Artillery systems do not fire smoke or other non-explosive projectiles.

3.0 PROCESSES FOR DYNAMIC CHANGES IN STATE VARIABLES

A number of processes are modeled in VECTOR which cause dynamic changes in values of the state variables. These are firepower processes; FEBA movement processes; supply consumption processes; weapon system, personnel, and supply replacement processes; reserve utilization processes; and tactical decision processes.[1] A number of processes can occur within an activity. Descriptions of these processes are essentially a description of how an activity is performed. This section describes which processes are contained in the model (with principal emphasis on the firepower processes) and lists their outputs.

3.1 Firepower Delivery Processes: The firepower processes describe different mechanisms of delivering firepower and their effects which cause changes in force composition values and supply levels. These processes may be grouped into four categories: air-to-air, ground-to-air, air-to-ground, and ground-to-ground. Descriptions of the processes in each of these categories are contained in VECTOR as submodels based on specific assumptions about the process being described. Inputs to each of these models are either directly measurable quantities or can be estimated from systems engineering models or more detailed combat process models.

The air-to-air firepower processes separately describe the interactions of the escort versus the interceptor duel and the interceptor versus the attack aircraft duel. Outputs of these submodels consist of the escorts continuing their mission, escorts killed, escorts who return without engaging interceptors, interceptors killed by escorts, interceptors killed by attackers, attackers killed by interceptors, attackers aborting missions, and attackers who continue on to perform their mission. These results are produced both by mission and aircraft type.

The ground-to-air firepower processes describe the interactions of air defense artillery against aircraft on missions to attack ground targets other than air defense sites,[2] air defense artillery versus aircraft on missions to suppress long-range air defense artillery, and the duel between attack helicopters and ground maneuver forces. The first two firepower processes consider the effects on the aircraft during the flight to its target, while in its target's area, and the return flight; and generate the fraction of aircraft surviving to perform their mission, the fraction of aircraft that perform their mission which survive the return flight, and the fraction of long-range air defense sites suppressed. The model for the maneuver force-attack helicopter duels generates estimates of the number of maneuver force weapons attritted, by type, and attack helicopter attrition while supporting its ground forces.

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[1]DIVOPS also plays target acquisition processes and fire-support assignment processes in significant detail, while this detail is not present in VECTOR-1 (although included in VECTOR-2, now under development).

[2]By aircraft type and mission.

The air-to-ground firepower processes separately describe the effect of attack aircraft against maneuver units at the FEBA and attack aircraft against other targets such as reserves, supplies, aircraft at air bases, shelters at air bases, etc. The model describing the firepower process against ground forces generates estimates of surviving numbers of weapon systems by type in the target force for all types of elements in the target.[1]

The ground-to-ground firepower processes include artillery against maneuver forces at the FEBA, artillery against other targets (other artillery, etc.), maneuver force delays and withdrawals, and maneuver force assault activities. The model describing artillery effects against maneuver forces at the FEBA generates estimates for the expected fraction of surviving forces in a battalion-sized maneuver force (by weapon system type and personnel in that unit), and the model describing artillery effects against other targets generates estimates of the expected fraction of the target and associated personnel surviving. Results of ground-to-ground firepower processes in delay and withdrawal activities may be determined outside the model and used as look-up tables for each activity in the model, or may use the general small unit action model described below.

The firepower (and other) processes in the assault activity between maneuver forces at the FEBA are computed internally, using VRI's differential models of combat. These models describe the dynamics of small unit firefights at the FEBA in great detail. The models explicitly consider different weapon system types on each side (tanks, anti-tank systems, mounted infantry, etc.), characteristics of these weapon systems (their firing rates, accuracy of fire, projectile flight times, lethality of the projectile), vulnerability of the target by type, firing doctrine of the weapon system (single rounds, burst fire, volley), probabilistic acquisition of targets in the firefight, allocation priorities of weapon systems to targets, maneuver of the weapon systems, and the effects of terrain line of sight on acquisition and fire capabilities. The combat model can be used with any of a number of scenarios corresponding to different terrain types, force types (armor, infantry, airborne, etc.), or other situational variations. The choice of scenarios is governed by the user-specified tactical decision rules. Each scenario determines the basic terrain characteristics, initial weapon placements, maneuver tactics, etc. which will be used in the evaluation of the small-unit action. The model computes attrition of weapon systems by type and personnel for the opposing units at different range steps as the assaulting unit closes to the objective (typically calculating results for periods of the order of 8 to 40 seconds). Based on tactical decision rules, the assaulting force may break off the assault or may stop and call for fixed-wing air, artillery, or attack helicopter fire support. Output of this model is a complete description of the surviving weapons systems by type and personnel at the end of the assault activity.[2]

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[1]Both permanent and repairable or temporary damage can be played for artillery and air defense systems attacked. Models (mathematical logic) exist to play varying damage for other targets, but have not been implemented and used in any of the computer programs.

[2]This model can be separately run as a small unit action model. Slightly different versions of it have been extensively used in this role since 1969 and have been shown to predict the mean results achieved from more detailed Monte Carlo simulations.

3.2 FEBA Movement Process: The FEBA movement process is considered in two parts: the decision for a maneuver force at the FEBA to move and the movement rate, given a decision to move has been made. A decision to move is based on a tactical decision rule which can be dependent upon many state variables. Given the decision to move, movement is computed by looking up an appropriate movement rate from the twelve movement rates accepted as input to the model. These movement rates are different, depending upon the activity being performed (advance, pursuit, successful assault, etc.) for each of the maneuver forces at the FEBA. This model was chosen entirely because of serious data limitations. As an alternative, the tactical decision rule feature discussed in section 3.6 may be used to govern movement in ways based on more complex dependencies.

3.3 Supply Consumption Process: Consumption of supplies occurs as a result of combat activity and as a result of the passage of time. Consumption during combat is computed separately for the assault activity and other combat activities. Consumption during the assault activity of a maneuver force at the FEBA is computed at each range step in the differential models of combat based on the expected number of rounds fired to achieve the expected attrition calculated in that model. In other combat activities, expenditure of supplies is computed on the same basis as its associated firepower process model. For example, if the firepower model gives effects on a per sortie basis, parallel data items give ammunition and POL expenditure per sortie. Consumption of supplies based simply on the passage of time is intended to simulate combat activities that are not included in the model. This type of consumption for units is in direct proportion to its personnel and weapons system strengths.

3.4 Replacement of Weapon Systems, Personnel, and Supplies: Available weapons systems, personnel, and supplies are bookkept with weapons systems and personnel in the sector reserve forces and they are used as replacements for battalion maneuver forces at the FEBA. This is accomplished by tactical decision rules in any of five ways. In each method, the rules first determine directly the available replacement weapons for each type of battalion for the period. Then, the rules may call for (1) direct replacements to individual battalion areas, (2) averaging the number of weapons and personnel among all "battalions" of the same type in the same sector, (3) assignment of the replacement in proportion to the difference of the present level in a "battalion" from its TO&E level, (4) assignment of the replacement in proportion to another rule determined measure of the "battalions" required replacements (e.g., 90% of TO&E level), and (5) assignment of replacements which approximate the results of assigning replacements to "battalions" so that no "battalion" loses weapons and all "battalions" are brought as close to a constant number of weapons (of the type concerned) as possible. Replacement of weapon systems, personnel, and supplies to the sector stores from the theater stores are modeled by similar tactical decision rules.

3.5 Reserve Utilization Process: Tactical rules determine the retirement of maneuver forces at the FEBA into the reserve and the commitment of reserves or new units to the FEBA. If as a result of retirement or commitment of a maneuver force at the FEBA in accordance with user-input

rules, the model finds a maneuver force at the FEBA temporarily without an opponent, the Red forces are redistributed into one more or one fewer of its allocated units. A force is distributed only into forces of the same type (there are up to ten types of Red and Blue units in a sector). In creating a new composite force, every force of the same type in the same sector loses a constant fraction of its weapons and personnel in such a way that the new "battalion" has the mean strength of all forces in the sector. In redistributing an excess Red "battalion," equal fractions of it are distributed to each other Red force of the same type in the same sector.

3.6 Tactical Decision Processes: The model contains a number of tactical decision rules which attempt to describe the behavioral tactical decision processes which are an integral part of any military activity. Recognizing that little is known regarding how military commanders actually make tactical decisions, the model provides the user with a lot of flexibility to specify realistic tactical decision rules for use in the model. A tactical decision rule is a rule that associates a decision (a choice among alternative courses of action) with a set of input conditions on state variables or functions of state variables. The user has complete flexibility to specify which state variables are to be considered in the rule and the manner of using them. Essentially, the user can set the value of any state variable as a function of the values of any other state variables contained in the model. Tactical decision rules in BATTLE are used to allocate forces and supplies to sectors; determine which maneuver forces at the FEBA will retire to the reserves; determine how many maneuver forces in reserve will go to the FEBA; govern the assignment of weapons and personnel to maneuver forces at the FEBA as replacements; assign theater intentions and plans for maneuver forces at the FEBA; determine activities of maneuver forces at the FEBA; determine fixed-wing tactical air, artillery, and attack helicopter assignments to missions; determine whether forces engaged in an assault (fixed defense) will call for support and when they will break off; and coordinate unit movement so as to control the FEBA shape.

4.0 MODEL INPUT, OUTPUT, AND REVIEW PROCEDURE

4.1 Model Input and Output: Cateogries of inputs to the VECTOR models are weapon performance data, tactical rule data, terrain data, and initial force inventory and deployment data. Outputs provided in the current version of the model include:

(1) Daily and cumulative weapon system losses by weapon type.

(2) Daily and cumulative casualties.

(3) Supply totals by type of supply.

(4) Total weapon system survivors by weapon type.

(5) Total personnel survivors in maneuver units.

(6) Total rear-area personnel survivors.

(7) Numbers of task forces, weapons, and personnel in reserves.

(8) Numbers of sorties flown on each mission by each aircraft type.

(9) For each battalion area maneuver unit (daily):

Number of weapon systems (by type), personnel and supplies

FEBA position

Activity

(10) Casualties (by location) and weapon system (by type) losses by system type which inflicts the attrition.

Additional more detailed output (or special summaries) can be produced as required by the user. Thus far, each use of the model has involved the use of one or another special outputs appropriate to the analysis being conducted. The model has been constructed to provide the capability to continue this type of usage.

4.2 Human Review Procedure: Recognizing that the tactical decision rules may at times result in some anomalies during the course of a long war or that the user may wish to change a particular decision during the course of a large-scale battle, a human review procedure allows the user a capability to replay a campaign with modifications. The user can direct that any state variable be set to a new value at a specified time or under specified conditions during a war. This might, for example, be used to change an originally specified allocation variable or an inappropriate theater intention.

5.0 EXTENSIONS IN VECTOR-2

VECTOR-2 is the third in an evolutionary series of models which includes VECTOR-0 and VECTOR-1. The purpose of the development program for VECTOR-2 was to remove some of the purposeful simplifications still remaining in VECTOR-1. In particular, the goal of the VECTOR-2 development was to include explicit representation of command and control, communications, and intelligence/target acquisition in the VECTOR models. Conceptualization of these extensions has been completed and they are currently being implemented. The following paragraphs describe the basic differences between VECTOR-2 and the earlier VECTOR models.

5.1 Structural Differences: Three basic structural additions provide the capability to represent the processes of command, control, communications, and intelligence/target acquisition in VECTOR-2. First, the entire command hierarchy from theater level to battalion level is explicitly represented. This representation allows explicit play of the command and control process from one command level to another. Secondly, a more detailed representation of battlefield geometry is used in VECTOR-2 than was played in VECTOR-1.

While the concept of sectors is retained from VECTOR-1, segments or battalion areas are replaced with *arenas*, each of which is an area whose width is that in which a battalion task force might operate,[1] and whose length is determined by the location of an objective (such as a bridge, hill, or terrain feature) at the end of the arena. Each arena is assumed to contain one or more *defensible positions* at which maneuver unit combat can occur. The terrain classifications used in VECTOR-1 are retained in VECTOR-2, but terrain need be uniformly classified only within an arena, not across an entire sector. In addition to the arena concept, additional geometry in VECTOR-2 is provided to allow forces in the rear area to be located more explicitly. The third structural difference which distinguishes VECTOR-2 from the previous models in the series is the use of an additional essentially continuous clock which allows representing the sequencing of events in a sector within a single model time period. This allows representing such time-dependent processes as communications (and the inherent time lags in the receipt of information) and the acquisition and allocation of fire to rear-area targets.

5.2 Forces Represented: Additional types of forces are represented in VECTOR-2 which were not included in earlier models in the series. Maneuver forces can now contain twelve types of weapon systems, and may include air defense weapons and attack helicopters as well as the types representable in VECTOR-1. Artillery forces in VECTOR-2 can contain up to four weapon system classes. Air defense artillery forces can contain up to six classes of weapons.

5.3 Processes Represented: VECTOR-2's additional structure as described in section 5.1 has allowed representing the processes of command and control, communications, and intelligence/target acquisition. Included in this representation is the explicit modeling of reserve commitment, the explicit allocation of fire support to acquired targets (including ones in the rear area), the impact of erroneous or late information on tactical decisions, etc. In addition, many of the process models already included in VECTOR-1 have been enriched. For example, the air-to-air firepower process model has been made more realistic by allowing many-versus-many aircraft duels; and several of the ground-to-ground firepower processes are represented in greater detail than in VECTOR-1.

6.0 EXPERIENCE WITH THE MODELS

Both VECTOR-0 and VECTOR-1 are written in American National Standards Institute (ANSI) FORTRAN and have been run on CDC 6400 and IBM 360/67 computing systems.[2] Versions of each now exist running with 52,000 words of memory. The models require two to three seconds of CPU time per sector per day of combat, plus additional CPU time if extensive output is desired.

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[1]However, unlike the segments of VECTOR-1, multiple Blue units may operate in a single arena if it is tactically appropriate to do so. Thus, forces may be massed within an arena.

[2]VECTOR-1 and its Data Preprocessor is currently being converted to run on the HIS 6000 computer system at the National Military Command System Support Center (NMCSSC).

(Some cases have run more than five CPU seconds per sector per day when extremely detailed output was required.) Typical total running times are from 3 to 20 minutes.

VECTOR-2 is currently being implemented in ANSI FORTRAN and is expected to be operational on CDC 6400 and IBM 370/168 computers later this year.

In the course of running VECTOR-0 and VECTOR-1, several methodologically significant observations have been made. Some of these are discussed in the following paragraphs.

6.1 Attrition is Not Uniform: The various systems are not attrited in proportion to their numbers. Further, the attrition caused by a single system type is not distributed in constant proportions across other systems.[1] Thus, this model, which examines attrition processes in detail differs significantly from most or all others in its predicted attrition results. This difference corresponds reasonably to the difference between the detailed predictions of small-scale combat models and the hypothesized mathematical forms which have often been used for these results in larger aggregated models.

6.2 Individual System's Effects Observable: The effects of individual system types on the outcomes of a theater-level campaign are clearly observable and bear clear relation to the input performance assumed. An example of this can be seen in the following case: a test case hypothetical combat was run where one of the two opposing forces heavily outweighed the other in armor, but the weaker-armor force possessed a hypotheical high-lethality, low vulnerability anti-armor helicopter. Figures 1 through 4 show some summary results of a run with these forces. As they show if overlayed, the initial attrition of armor helicopters is severe, and can in fact cause some movement of the FEBA in favor of the weaker armor force, but as the helicopters are attritted, the resupply, mobilization, recovery, and repair of armor (as input in this run) for the strong-armor force again causes a significant change in the combat conditions.

6.3 Sensitivity and Trade-Off Analyses Possible: Because no direct human gaming is required and the model runs quickly, large numbers of runs can be made in the analysis of procurement, deployment, force design, or tactical questions. One of the kinds of output that can be used in procurement and force design is illustrated in figures 5 and 6, where the effects of variations in the numbers of tactical aircraft and attack helicopters on one specific hypothetical combat of ten days duration are displayed. Comparison of the two graphs does demonstrate one serious difficulty associated with such analyses -- the comparative marginal effectiveness of the systems is very sensitive to the performance measure used. This limitation was made even more clear when portions of this analysis were re-run for combat durations of up to 100 days and changes in comparative marginal effectiveness on the same measures of performance were greater than two orders of magnitude. (It may be worth noting that the entire set of runs used in these trade-off analyses, about 90 runs, were produced in two evenings of computer runs.)

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[1]These points have been most clearly observed with some of the detailed outputs from DIVOPS, but can also be seen in VECTOR.

6.4 Results are Sensitive to Tactical Rules: Although no extensive analysis of their effects has been carried out to date, the analyses that have been made show that the overall combat results of these models are sensitive to reasonable changes in the input tactical decision rules in almost every area. This sensitivity reflects the potential sensitivity of campaign outcomes to force missions, strategies, and tactical behavior. It should be noted here that the input rules should represent behavioral assumptions, not doctrinal ones -- unless deliberately made. There need be no assumption that the forces in the model can make intelligent, doctrinally correct decisions without hesitation. (Perhaps this observation will answer some of the recent comments that have implied that models cannot play commanders who are not perfect and/or differences in training and ability in decision making processes.)

Overall, it has been the impression of the designers and all those who have used these models that they provide a flexible tool to examine the detailed interactions of tactics and weapon performance in a theater-level campaign and that they provide a structure in which the causal links of the observed output to the input are easily determined for analyses.

More detailed information on the models discussed here may be found in

(1) Bonder, S., and Honig, J., "An Analytic Model of Ground Combat: Design and Application," *Proceedings of the 27th MORS*, Military Operations Reserach Society, Montgomery, Alabama, June 1971, pp. 73 - 107.

(2) Systems Research Laboratory, *Development of Analytical Models of Battalion Task Force Activities*, S. Bonder & R.L. Farrell (eds.), Report No. SRL 1957 FR70-1, Department of Industrial Engineering, the University of Michigan, Ann Arbor, Michigan, September 1970.

(3) Vector Research, Incorporated, *Analytic Models of Air Cavalry Combat Operations*, Vols, I&II, Report No. SAG-1 FR 73-1, Ann Arbor, Michigan, May 1973.

(4) _____, *VECTOR-0, The BATTLE Model Prototype*, Vols. I-V, Weapons Systems Evaluation Group (WSEG), Report No. 222. Arlington, Virginia, December 1973.

(5) _____, *DIVOPS: A Division-Level Combined Arms Engagement Model*, Report No. ARAFCAS-1 TR 74-1, Volumes I-III, Ann Arbor, Michigan, 1 December 1974.

(6) _____, *VECTOR-1, A Theater Battle Model: Volume I, A User's Guide*, Weapons Systems Evaluation Group (WSEG), Report No. 251, Arlington, Virginia, July 1974.

Documentation of VECTOR-2 will be available later this year.

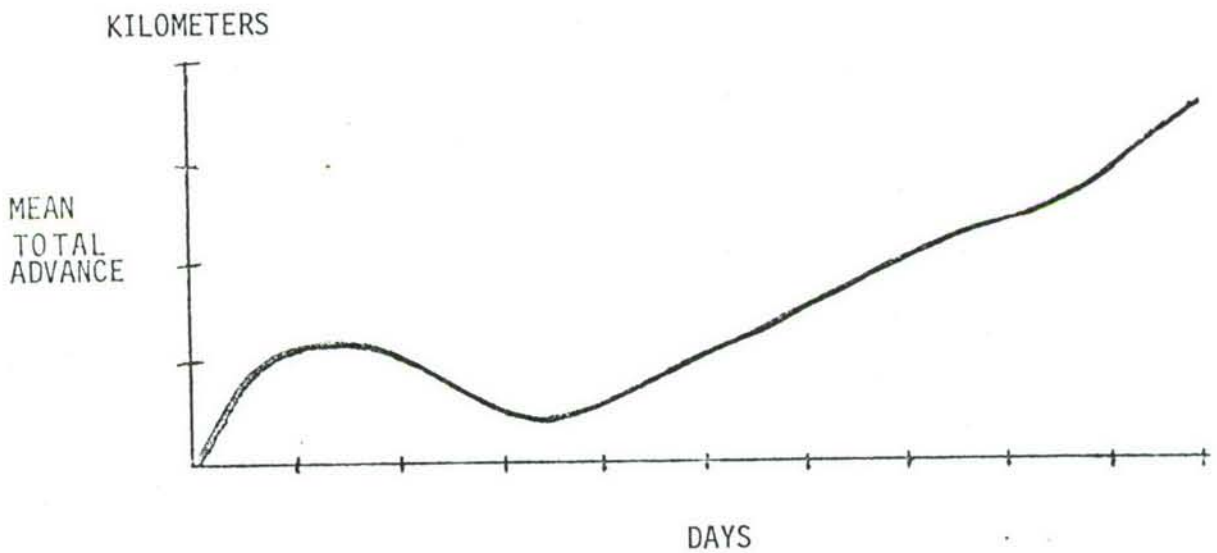


FIGURE 1. A HISTORY OF FEBA MOVEMENT IN A HYPOTHETICAL CAMPAIGN

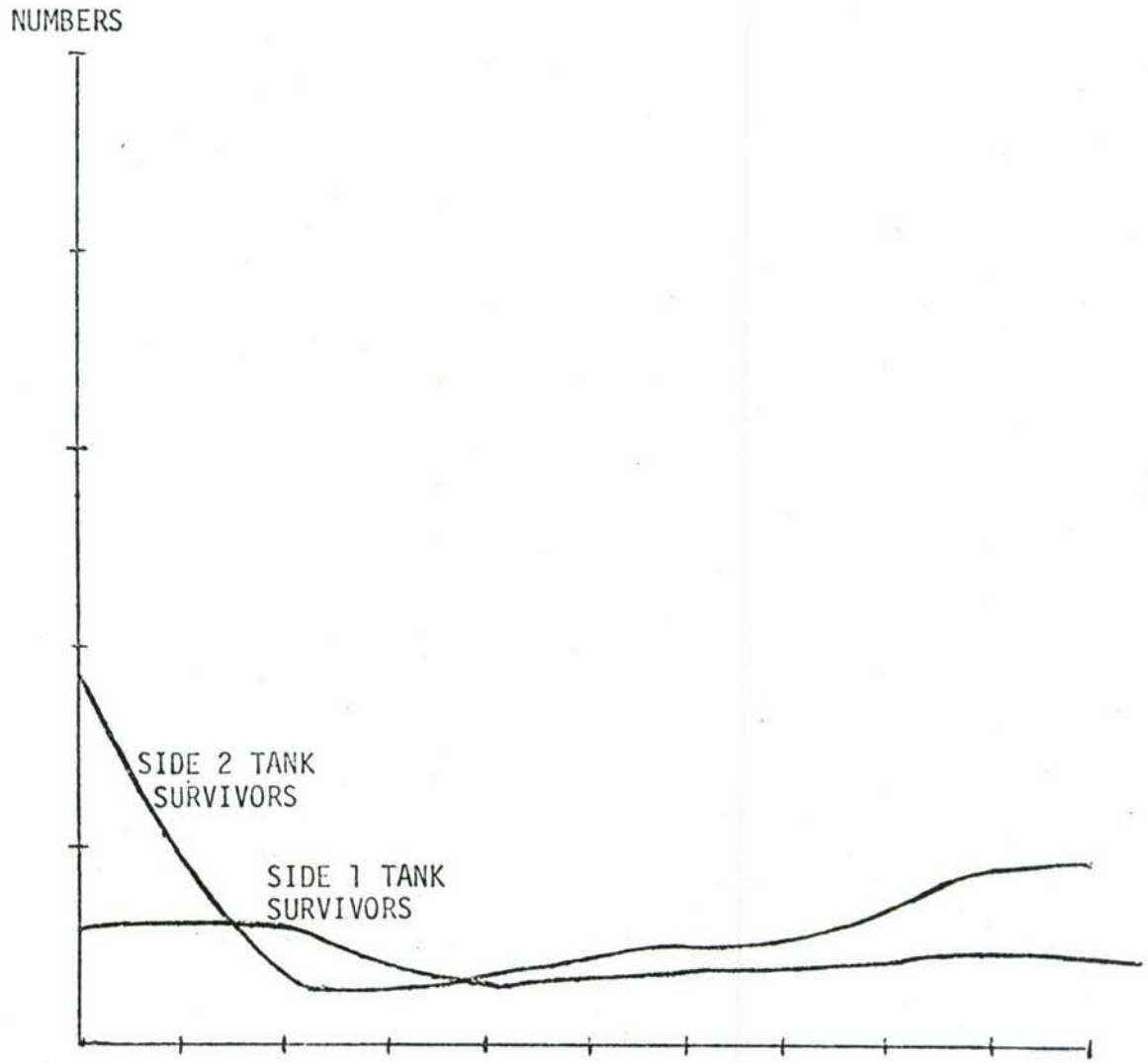


FIGURE 2. A HISTORY OF TANK SURVIVORS IN A HYPOTHETICAL CAMPAIGN

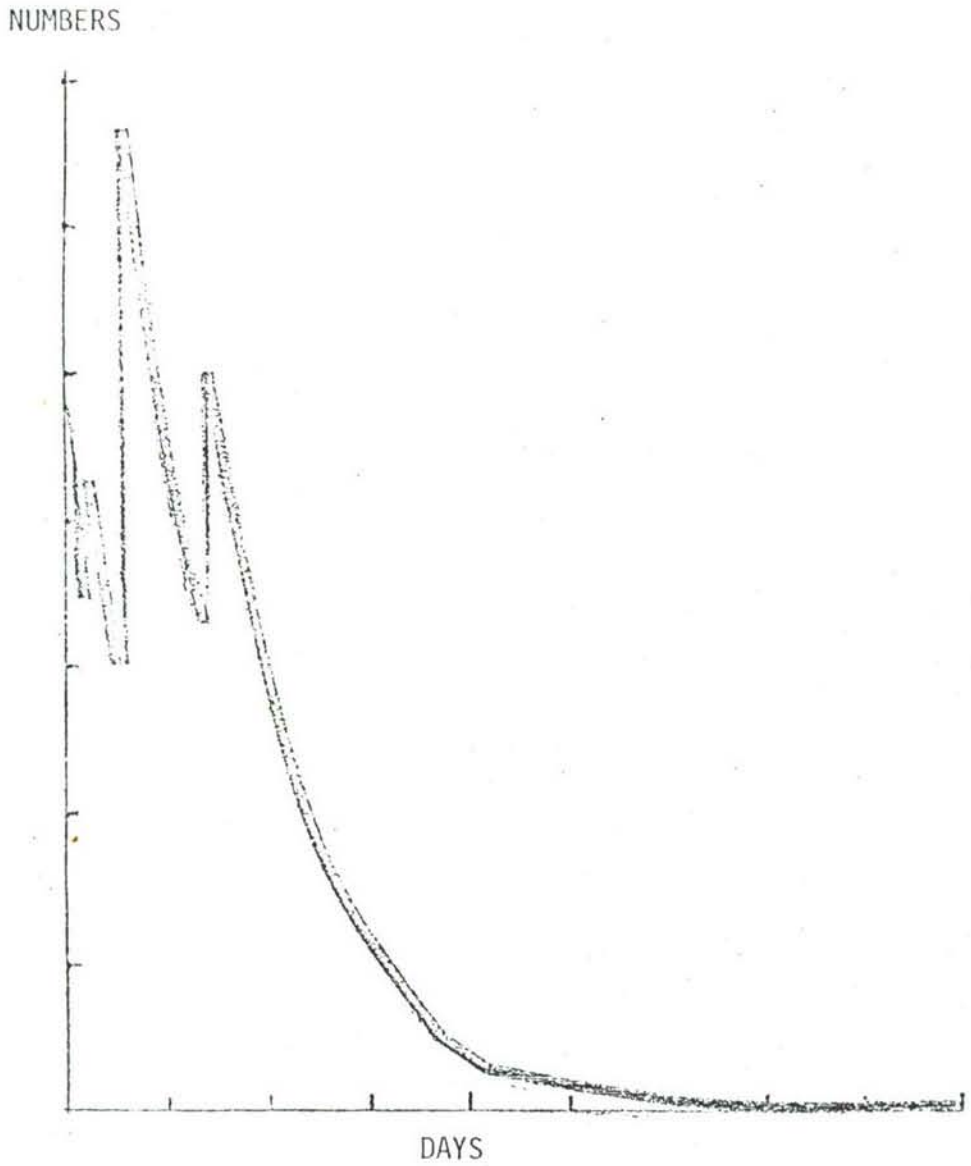


FIGURE 3. A HISTORY OF ATTACK HELICOPTER SURVIVORS IN A HYPOTHETICAL CAMPAIGN (SIDE 1)

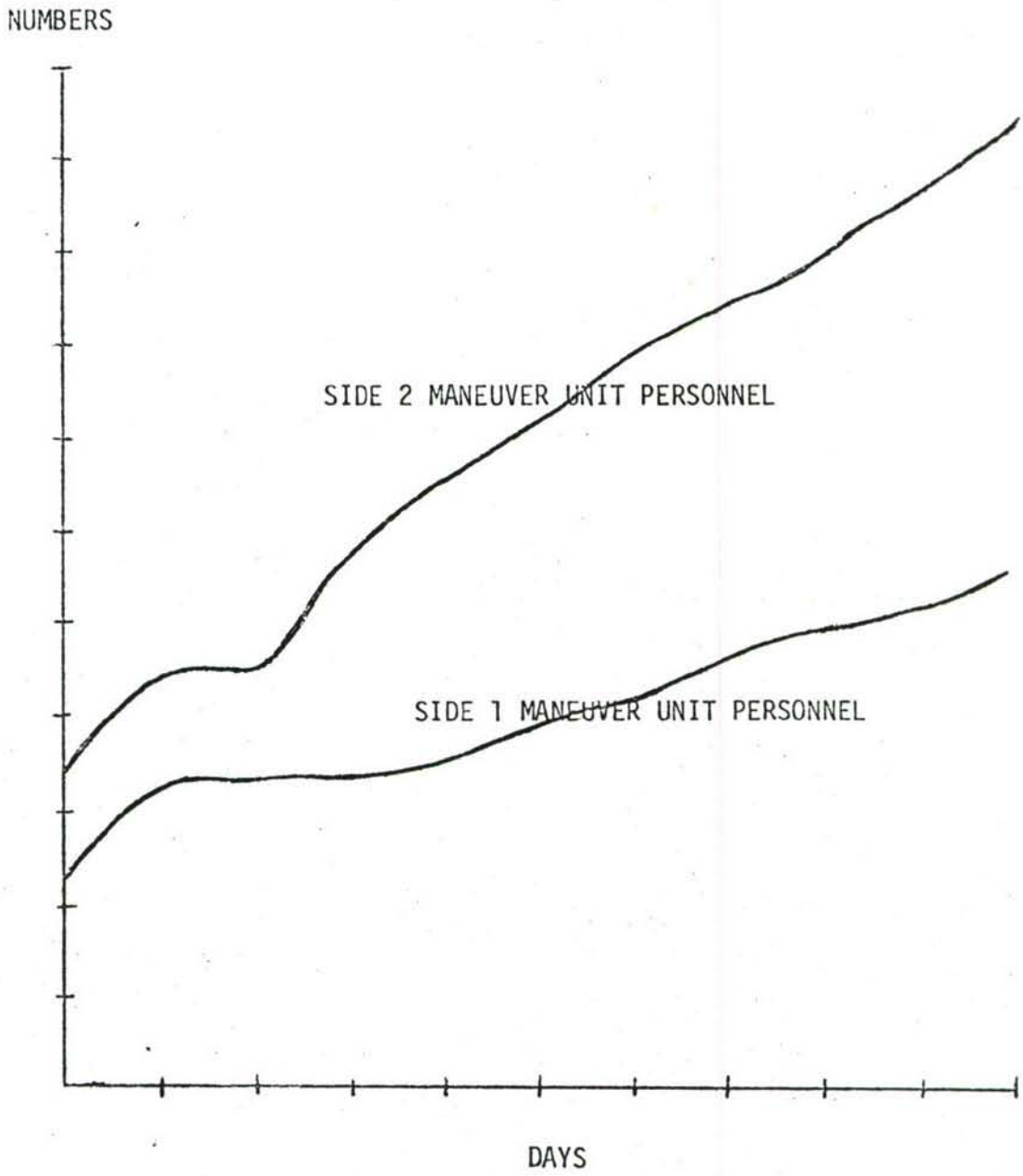


FIGURE 4: A HISTORY OF MANEUVER UNIT PERSONNEL SURVIVORS IN A HYPOTHETICAL CAMPAIGN

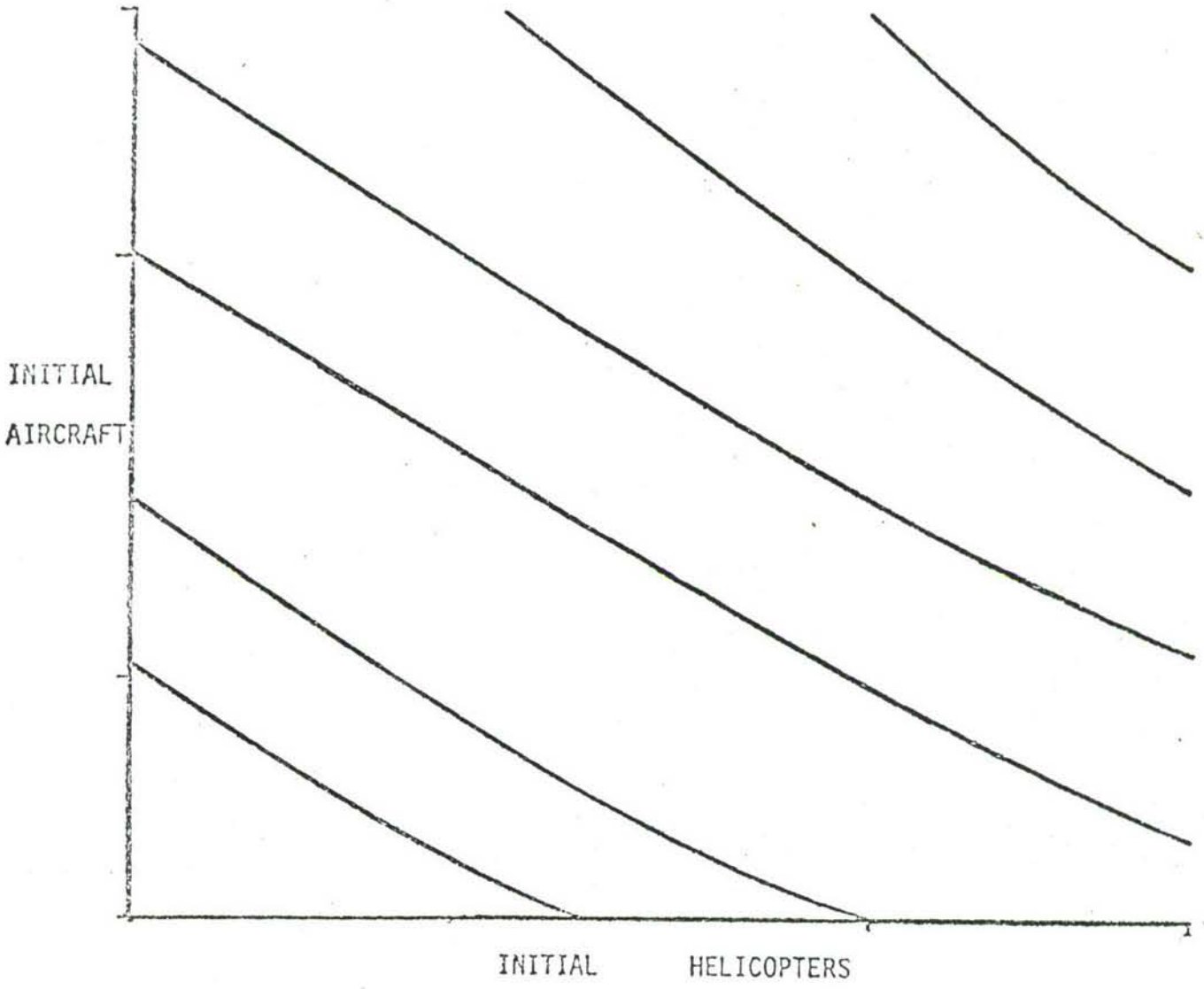


FIGURE 5.

ISO-EFFECTIVENESS CONTOURS AS INITIAL AIRCRAFT AND HELICOPTERS ARE ALLOWED TO VARY. THE EFFECTIVENESS MEASURE FOR THIS GRAPH IS THE NUMBER OF RED TANK LOSSES BY DAY 10.

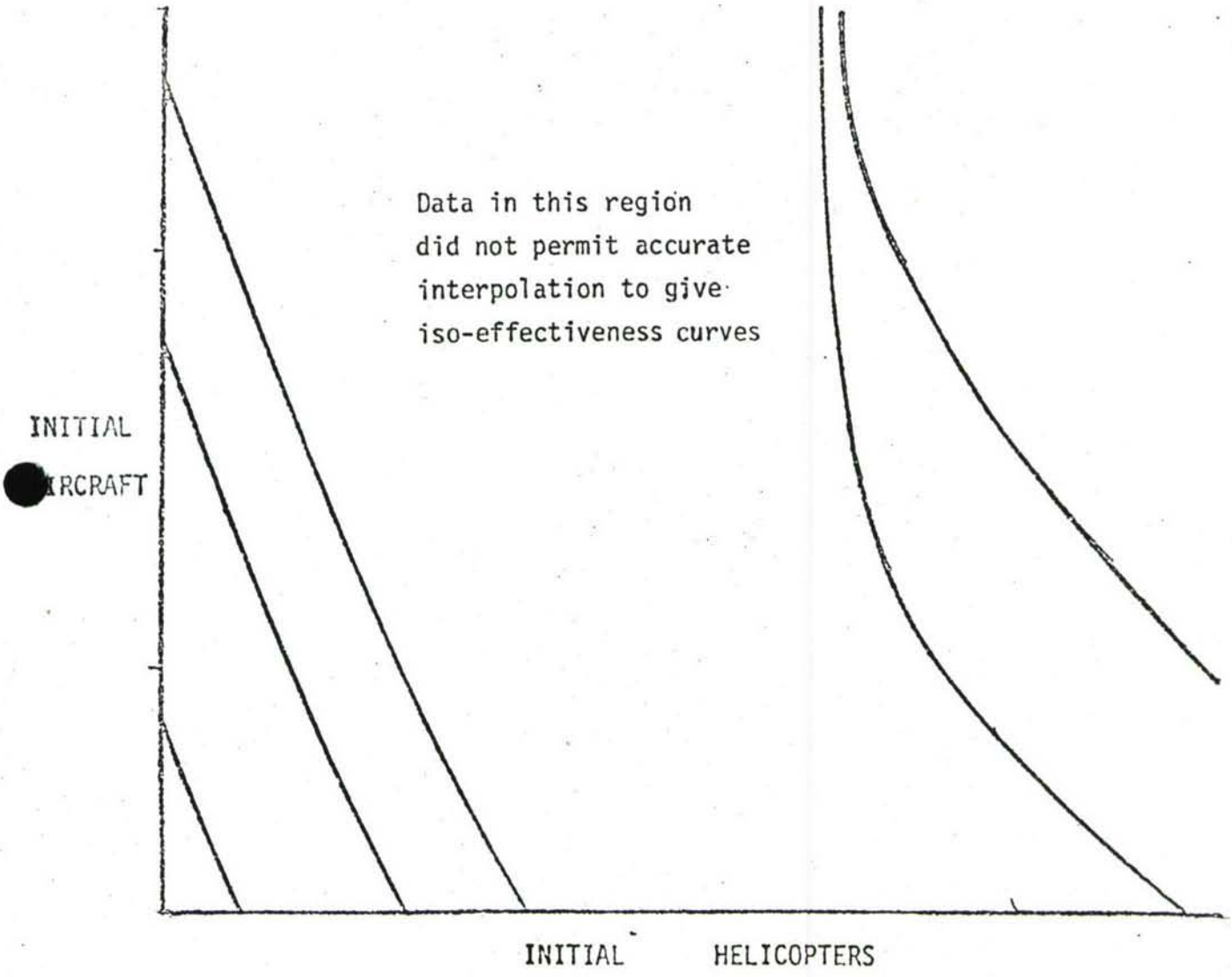


FIGURE 6.

ISO-EFFECTIVENESS CONTOURS AS INITIAL AIRCRAFT AND HELICOPTERS ARE ALLOWED TO VARY. THE EFFECTIVENESS MEASURE FOR THIS GRAPH IS THE MEAN FEBA LOSS BY DAY 10.